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SAND2006-5674
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Printed October 2006

Spent Fuel Sabotage Aerosol Test Program: FY 2005-06 Testing and Aerosol Data Summary

Martin A. Molecke, John E. Brockmann, Daniel A. Lucero, Michele Steyskal, Michael W. Gregson, Michael C. Billone, T. Burtseva, Wolfgang Koch, Oliver Nolte, Gunter G. Pretzsch, Wenzel Brücher, Bruno A. Autrusson and Olivier Loiseau

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ABSTRACT

This multinational, multi-phase spent fuel sabotage test program is quantifying the aerosol particles produced when the products of a high energy density device (HEDD) interact with and explosively particulate test rodlets that contain pellets of either surrogate materials or actual spent fuel. This program has been underway for several years. This program provides source-term data that are relevant to some sabotage scenarios in relation to spent fuel transport and storage casks, and associated risk assessments. This document focuses on an updated description of the test program and test components for all work and plans made, or revised, primarily during FY 2005 and about the first two-thirds of FY 2006. It also serves as a program status report as of the end of May 2006. We provide details on the significant findings on aerosol results and observations from the recently completed Phase 2 surrogate material tests using cerium oxide ceramic pellets in test rodlets plus non-radioactive fission product dopants. Results include: respirable fractions produced; amounts, nuclide content, and produced particle size distributions and morphology; status on determination of the spent fuel ratio, SFR (the ratio of respirable particles from real spent fuel/respirables from surrogate spent fuel, measured under closely matched test conditions, in a contained test chamber); and, measurements of enhanced volatile fission product species sorption onto respirable particles. We discuss progress and results for the first three, recently performed Phase 3 tests using depleted uranium oxide, DUO_2, test rodlets. We will also review the status of preparations and the final Phase 4 tests in this program, using short rodlets containing actual spent fuel from U.S. PWR reactors, with both high- and lower-burnup fuel. These data plus testing results and design are tailored to support and guide, follow-on computer modeling of aerosol dispersal hazards and radiological consequence assessments. This spent fuel sabotage – aerosol test program, performed primarily at Sandia National Laboratories, with support provided by both the U.S. Department of Energy and the Nuclear Regulatory Commission, had significant inputs from, and is strongly supported and coordinated by both the U.S. and international program participants in Germany, France, and the U.K., as part of the international Working Group for Sabotage Concerns of Transport and Storage Casks, WGSTSC.

ACKNOWLEDGEMENTS

The authors wish to acknowledge and express gratitude to the major contributions and support by multiple people to the ongoing conduct and updating of this surrogate/spent fuel sabotage and aerosol measurement test program. All of the participants of the international Working Group for Sabotage Concerns of Transport and Storage Casks are responsible for the continuing successes of this program. Most of the same people have also provided major technical inputs to the writing of this report, analyses of the data within, plus designs and fabrication for many of the test components. We also recognize Sandia National Laboratories personnel from the Explosives Components Facility: Marc Hagan, explosives technician; Roy Dickey, explosives engineer and components designer, plus Lloyd Bonzon, explosive projects department manager, both retired at the end of 2005; and, Manny Vigil, retired, consultant, for providing significant guidance on the science of the explosive components and processes, and for providing excellent test program support. Mai Luu and Traci Durbin, Aerosol Sciences, Sandia Department 1517, also provided very valuable aerosol and testing support. Kevin Ewsuk and Denise Bencoe, Ceramic Processing and Inorganic Materials Department 1815, provided key support on cerium oxide pellet and fission product-doped pellet fabrication, as well as technical support and guidance. Lorraine Herrera, Department 6146, provided key support in shipping test samples to the analytical chemistry laboratory, coordinating the analyses and results, and converting data received into the required formats and figures required for our full interpretations.

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1. INTRODUCTION

This document provides a detailed overview, results, and near-term plans for an ongoing, multi-national test program that is measuring aerosol particle data for several spent fuel sabotage scenarios relevant to spent fuel transport and storage casks. The casks used for spent nuclear fuel transport are extremely resistant to releasing any significant fraction of their contents, even in very severe accident conditions. However, in some credible sabotage scenarios, such as an attack employing high energy density devices (HEDDs), i.e., explosive armor-piercing weapons, it is possible that a small percentage of aerosolized particles from disrupted fuel pellet materials could be released. If released to the environment in a significant quantity, the particulated spent fuel respirable particles have the potential to cause radiological consequences. Measurement of the actual amounts, nuclide content, and size distribution of the released materials from spent fuel is essential for predicting the significance of the radiological impacts. These source-term data are the input for follow-on modeling studies to quantify respirable hazards, associated radiological risk assessments, vulnerability assessments, and potential cask physical protection design modifications. The need for accurately quantifying this information has been strongly supported by program participants in the U.S., Germany, France, and the U.K., as part of the international Working Group for Sabotage Concerns of Transport and Storage Casks (WGSTSC). WGSTSC partners need, and are helping to coordinate this research to better understand potential radiological consequences, and to support subsequent risk assessments, detailed modeling, and to develop potential preventative measures from plausible sabotage events.

Sandia National Laboratories (SNL, Albuquerque, New Mexico) Materials Transportation Testing and Analysis Department 6141, has the lead role for managing and performing this research program. Other SNL Departments providing required expertise, engineering, fabrication, testing, and facilities are: Dept. 2554, Explosive Testing and Diagnostics; Dept. 1517, Aerosol Sciences; Center 1300, Radiation Sciences (Nuclear Facilities, Engineering ,and Technologies, Departments 1382-1384); Ceramic Processing and Inorganic Materials Department 1815; and, Radiation Protection Department 10328.

Overall sabotage and transportation program support is provided by both the U.S. Department of Energy (DOE), Office of Civilian Radioactive Waste Management (OCRWM), RW Office of National Transportation, and National Nuclear Security Agency (NNSA)/ Office of International Safeguards) and the U.S. Nuclear Regulatory Commission (NRC), Offices of Nuclear Regulatory Research, and Nuclear Security and Incidence Response. Argonne National Laboratory (ANL), Energy Technology Division, has provided the detailed characterization and fabrication work for all spent fuel test rodlets to be used in this program. German participants, the Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) and the Fraunhofer Institute of Toxicology and Experimental Medicine (ITEM), are providing supporting aerosol testing, expertise, and data analyses. The Institut de Radioprotection et de Surete Nucleaire (IRSN), France, has provided unirradiated depleted UO_2 (surrogate, DUO_2) fuel test rodlets for Phase 3 testing plus supporting modeling studies. The Office for Civil Nuclear Security (OCNS), in the UK, participates in a consultative role.

A major purpose of *this* document is to provide an update and extension to the FY 2004 document [Molecke et al., 2005a] that detailed this ongoing, multi-phase test program and the results ob-

tained to date. We shall focus on new developments in test program design, test apparatus improvements, and document all the available data obtained over about the past year and two-thirds, FY 2005 and the first eight months of FY 2006. We shall present significant detail and test apparatus descriptions for the first three, recently initiated (October 2005) Phase 3 tests which include unirradiated, depleted uranium oxide and the upcoming, Phase 4, actual spent fuel aerosol-explosive tests. We shall minimize repetition of test details provided in earlier summary reports [Molecke et al., 2004a; Molecke et al., 2005a]. In addition, the goals and objectives of this spent fuel sabotage aerosol measurements program and a summary of the historical background of related tests that built the foundation of the current test program were also documented previously [Molecke et al., 2004a], and will not be repeated.

2. DATA NEEDS

Aerosol particle testing requires sampling and measurement of the mass and physical characteristics of the aerosol particles produced from (spent fuel or surrogate rod) target-HEDD jet impact, with particle aerodynamic equivalent diameters (AED) up to 100 μm (micrometers). The AED is defined by means of the settling velocity of a unit density sphere, and is equivalent to the particle geometric-diameter times the (particle density)$^{1/2}$. For evaluations of aerosol and radiological consequences, there has always been a special emphasis on respirable particles, commonly defined as 0 to ≤ 10 μm AED in size. Respirable particles also have been sub-categorized into the *respirable* portion (or fraction), 0 to ~ 4 μm, and the *thoracic* portion, ~ 4 to ~ 10 μm AED. Data from the coarser aerosol particles in the ~ 10 to 100 μm AED range, termed the *inhalable* portion, are of interest primarily for radiological "ground-shine" (dispersion, soil contamination, potential ingestion) consequence estimates. Particles larger than 100 μm are not considered to be aerosols. Multistage aerodynamic particle sizing devices (impactor collectors) are used to classify aerosol particles according to their aerodynamic diameter. We initially used Respicon virtual impactors and Berner impactors [Molecke et al., 2004a]; all aerosol data obtained in FY 2005 and FY 2006 used only multi-stage Marple impactors and custom designed large particle separators (LPS), and will be described later.

This experimental program is designed to measure several important features of the interaction of a HEDD (conical shaped charge, CSC) jet with spent fuel or surrogate material pellets contained within a Zircaloy-4™ cladding tube. The source-term data measured includes:

1. The **Respirable Fraction (RF)**. There is special emphasis on the particle respirable fraction produced, defined as the mass of an element (i.e., for U, Ce, Zr, Cs, etc.) in respirable particles (0 - 10 μm AED) / total mass of that element in the rod volume swept (particulated) by the HEDD. This RF, usually expressed as a percentage, is particularly relevant to far-field (i.e., released from the damaged spent fuel cask), airborne dispersion and consequence modeling studies. The particle size distribution is also measured for all aerosol particles produced, as a function of chemical element, from 0 to 100 μm AED (aerodynamic equivalent diameter).

2. The measurement of a more accurate and precise value for the **Spent Fuel Ratio (SFR)** for respirable particles. The SFR is defined as:

SFR = [Spent Fuel respirable particle masses] / ["Surrogate" DUO_2 respirable particle masses]

The SFR determination is, essentially, the comparison of the respirable, aerosol particle data from irradiated fuel to unirradiated surrogate fuel. These data are obtained in paired experiments using the same apparatus, essentially identical test conditions, and using the same HEDD. The SFR will be calculated from respirable, aerosol particles collected in multiple size ranges, from 0 up to about 10 μm. The measured SFR values provide a data bridge to previous large-scale surrogate (DUO_2) cask tests [Lange et al., 1994, Sandoval et al., 1983] and consequence assessments. The SFR values permit scaling to other geometries, single fuel rod to rod bundles, by means of supporting modeling studies. The respirable particle masses for DUO_2 target rodlets is being quantified during FY 2006, the respirable particle masses for irradiated spent fuel rodlets in FY 2007. Therefore, measured determination of the SFR cannot be provided until 2007. A "Surrogate Ratio" value (SR, similar to the SFR) can also be calculated, as the ratio of respirable CeO_2 particles/respirable surrogate DUO_2 particles, for surrogate material test comparisons.

The primary test benefit of using the ratio of respirable, aerosol particles for the SFR determination is that it is not necessary to recover and analyze all of the aerosolized materials produced; only the identical portions of aerosol particles from both the spent fuel and surrogate fuel tests must be obtained, analyzed, and compared. This ratio drives the requirement for use of identical-as-possible test apparatus and test conditions for multiple test phases and materials. In addition, by focusing on the spent fuel ratio determination, we can use test rodlets containing only a few actual or surrogate fuel pellets for aerosol particle production. Entire fuel assemblies or casks full of fuel assemblies do not need to be tested.

3. The measurement of enhancement of volatile fission product nuclides like cesium and, to a lesser extent, ruthenium, preferentially sorbed onto specific, respirable particle size fractions in the sub-μm to μm size range. This enhanced sorption, integrated over the total respirable size range of 0-10 μm AED, is expressed as an **"Enrichment Factor" (EF)**, defined as:

$$\textbf{Enrichment Factor, } EF = RF_{\text{(fission product element)}} / RF_{\text{(uranium or surrogate cerium)}}$$

Enrichment Factors can also be calculated similarly as a function of measured particle size ranges, e.g., individually for 0 to 0.5 μm, 0.5-0.9 μm, 0.9-1.6 μm, 1.6-3.5 μm, 3.5-6 μm AED, etc.

3. TEST PROGRAM DESIGN SUMMARY

The overall test program plan and design was described and documented in Sandia Technical Report SAND2004-1832 [Molecke et al., 2004a]. That report identified the number and sequence of tests for the total program. It also documented test component plans and requirements as of the end of FY 2003. The FY 2004 test and data summary document SAND2005-4446 [Molecke et al., 2005a] provided an update and modest revision to that test plan. *This* FY 2005 and first-half of FY 2006 document provides the most recent additions and revisions to the test plan, *focuses* on these changes and the progress made, and presents data and interpretations generated during the most recent time period.

The overall program consists of four sequential test phases, Phase 1 through Phase 4. Individual tests in each phase use the identical type of HEDD, but different test materials with similar geometries. Successive phase testing has allowed the addition and evaluation of multiple test variables and target material (pellet) response to HEDD jets, and consequent aerosol particle production. All four test phases were previously described [Molecke et al., 2004a] in detail, as of the end of FY 2003. The following details focus predominantly on additions to, or modifications of Phases 2, 3, and 4 through March 2006.

Phase 1 testing was performed in 2001 and 2002 at Sandia National Laboratories and the Fraunhofer Institute, Germany. This test phase included: performance quantifications of the HEDD devices; characterization of the HEDD or conical shaped charge (CSC) jet properties with multiple tests; refinement of the aerosol particle collection apparatus being used; and, CSC jet-aerosol tests using leaded glass plates and glass pellets, serving as representative brittle materials. Phase 1 work, experimental results obtained, observations, and preliminary interpretations were documented in Sandia Technical Report SAND2005-5873 [Molecke et al., 2005b]. Phase 1 testing was quite important for the design and performance of the subsequent Phase 2 test program and test apparatus.

The extensive **Phase 2** tests use nonradioactive cerium oxide, CeO_2, as sintered ceramic pellets contained within Zircaloy cladding tube assemblies, similar to spent fuel rods. CeO_2 was selected as an excellent chemical "surrogate" and a representative ceramic material for UO_2 fuel material for pressurized water reactor fuel rods [Molecke et al., 2004a, Molecke et al., 2004b]. Twenty four Phase 2 surrogate material tests were conducted in the 2002 - 2004 period. During FY 2004, we completed Phase 2 of this test program with surrogate target materials, tests 2/5A through 2/8D. All of the results and interpretations to date were detailed in [Molecke et al., 2005a]. The Phase 2 test matrix, through test 2/8D, is listed in Table 3.1.

We also performed three **Phase 2 / Phase 3 cross-over tests** during 2004, tests 2/9A, 9B, and 9C; these added tests were, basically, an extension of the original Phase 2 program. These cross-over tests used non-radioactive CeO_2 test rodlets (with no dopant materials, in order to eliminate potential fission product species residual contamination in subsequent tests), and the new, optimized, Phase 3 aerosol-explosive test chamber, to be used for all the DUO_2 Phase 3 tests. These three tests were performed at the SNL Explosive Components facility and were intended as the initiation to, and operational practice for the Phase 3 tests that follow. The final two planned Phase 2 / Phase 3 cross-over tests, 2/9D and 9E, will be performed at the SNL Gamma Irradiation Facility, GIF, (anticipated during FY 2007) as operational handling and proof tests for the spent fuel Phase 4 test system; they will be handled in a "semi-remote" manner. The updated Phase 2 / Phase 3 cross-over test matrix is listed in Table 3.2.

The predominant aerosol-explosive testing performed during FY 2005-2006 included six new **Phase 2+** tests, tests 2/10A-2/10F. These Phase 2+ tests were added to the original program ma-

trix following discussions at the 8th Technical Meeting of the WGSTSC, in Albuquerque, during November 2004. Both the SNL and German test partners reported significant, but differing levels of cesium fission product dopant enrichment in the smaller aerosol particle sizes that was coincident with the copper (from the shaped charge jet) and explosive soot respirable particles. This information was originally documented at the WGSTSC Technical Meeting, in [Brockmann et al., 2005]. Consequently, Phase 2+ tests, using fission product-doped surrogate cerium oxide pellets, were specifically added to evaluate the release and enrichment of cesium, ruthenium, and strontium dopants with tests in a vented aerosol collection chamber configuration somewhat similar to the earlier Phase 2 tests in a semi-open square aerosol collection chamber [Molecke et al., 2004a], and to the German vertical elutriation apparatus [Molecke, et al., 2005b]. It is postulated that when the conical shaped charge is detonated within an enclosed test system, the presence of more explosive byproduct soot and an associated internal temperature rise may increase the extent of fission product enrichment onto the more plentiful respirable materials present. The expanded Phase 2 test matrix, including the Phase 2+ tests, is included in Table 3.1 for FY 2005-2006.

Table 3.1 Phase 2 and 2+ Tests: CeO_2 Surrogate Test Matrix

Test Phase 2: Cerium Oxide Surrogate Pellets/Rods				
Test #	Pressure	Dopants	Variables	Date
0	1 bar	no	top; system checkout	10/2002
1A, 1B	1	no	top, center; Respicon samplers	10/2002
2A, 2B	1	no	optimized for French pellet & tube size	12/2002
3A, 3B	1	no	optimized for U.S. pellet & tube size, Respicon & Berner samplers	7/2003
4A, 4B	1	yes	" + rev. equipment design, FP dopants	8/2003
5A – 5G	1	yes	" + vertical test chamber, instruments, Marple particle impactors.	9/03-1/04
6A, 6B	28-38 (blow-down)	yes	" + equipment design modifications, Marple impactors, Large Particle Sep.	4-5/2004
7A, 7B	1	yes	German HAW/HLW glass rod, dopants (nonradioactive)	2/2004
8A – 8D	1	yes	particle impactors & sampling optim.	2-4/2004
10A, 10B	1	yes, 6 FP disks	9 CeO_2 pellets, new, ½ size test chamber, check-out & replicate	4-6/05
10C, 10D	4 doped CeO_2 CsI, Ru, SrO, Eu_2O_3		+ 6 CeO_2 pellets, semi-open chamber, w/valved entrance port	7/05
10E, 10F	1	yes, in glass	**9 German HAW/HAW glass pellets** joint w/ Fraunhofer & GRS	8/05
10G, 10H	4 doped CeO_2 CsI, Ru, SrO, Eu_2O_3		+ 6 CeO_2 pellets, testing in Germany, to cross-calibrate vertical elutriator	2006

FY 2003 ⬆⬆⬆⬆

FY 2004 ⬆⬆⬆⬆

Phase 2+ FY 2005 ⬆⬆⬆⬆

The new, Phase 2+ series of surrogate tests are intended to resolve several variables and their effects on fission product dopant respirable production and enhanced sorption onto other respirables produced. The primary variables to be evaluated are:

A) The effect of the position of the conical shaped charge (CSC), either detonated outside of a semi-open aerosol chamber (similar to the 2/0 through 2/4 series of Phase 2 tests [Molecke, et al. 2004a], or similar test performed at the Fraunhofer Institut using the separate vertical elutriation chamber [Molecke, et al., 2005b], or detonated inside the sealed and co-joined Phase 2 aerosol collection chamber-explosive containment chamber ("Grandma") [Molecke, et al., 2005a] on the enrichment of cesium and other fission products.

B) The distribution homogeneity of the fission product dopant within the surrogate material pellet, whether distributed throughout the pellet (as in an actual spent fuel pellet, or within the doped, vitrified German glass rodlet (tests 2/7A and 7B [Molecke, et al., 2005a] or individual pellets (tests 2/10E and 10F, this report), or located at discrete, localized positions within fission product dopant disks adjacent to cerium oxide pellets.

Table 3.2 Phase 2 / Phase 3 Crossover Tests: Phase 3 Chamber + CeO_2 Surrogate

Test #	Pressure	Dopants	Variables	Date
2/9A	1 bar	no	new test chamber, 4 Marples & LPS, **in ECF**	8/2004
2/9B	1 bar N_2	no	Same, with inert atmosphere, **in ECF**	8/2004
2/9C	1 bar	no	"blank" w/Zirc tube, for post-test handling operations, 4 Marples & LPS	11/04
2/9D	1 bar	no	"blank" w/Zirc tube, **in GIF**, "as if" Phase 4 spent fuel, 4 Marples & LPS	2006-07
2/9E	1 bar N_2	no	"blank" w/Zirc tube, **in GIF**, same, w/ inert atmosphere	2006-07

Phase 3 tests use unirradiated, depleted uranium oxide (DUO_2) pellets in comparable, new Zircaloy cladding tube test rodlets. The overall Phase 3 aerosol-explosive test chamber is based on the similar, but less sophisticated Phase 2 chamber design(s). Three of these tests have been performed through March 2006 in the Sandia Explosive Components Facility, ECF, instead of in the Sandia Gamma Irradiation Facility, GIF, as described earlier [Molecke et al., 2004a, 2005a]. The remaining three Phase 3 tests are anticipated to be completed during FY 2007. The Phase 3 test matrix is listed in Table 3.3. The DUO_2 test rodlets were designed and fabricated by our French

Table 3.3 Phase 3 Tests: Advanced DUO_2 Surrogate Test Matrix

Test Phase 3: Depleted Uranium Oxide Pellets/Rods, from IRSN					
Test **(order)**	Rodlet	Pressure	Dopant	Variables	ECF Date
3/2 **(A)**	DUR-2	1 bar	no	air (in aerosol chamber)	10/14/05
3/5 **(B)**	DUR-5	40 (He)	no	air	1/12/06
3/1 **(C)**	DUR-1	1	yes	air	3/09/06
3/3 **(D)**	DUR-3	1	yes	N_2 (in aerosol chamber)	2007 (planned)
3/4 **(E)**	DUR-4	40	yes	air	2007
3/6 **(F)**	DUR-6	40	yes	N_2	2007

test partner, IRSN, and their contractor, CERCA (a subsidiary of Framatome-ANP), and are described in detail in Section 5.1. IRSN-designated rodlet name are also listed in Table 3.3.

Note that the Phase 3 testing "order," (A) to (F), in Table 3.3 is different than the test/rod numbers. This was modified in order to eliminate potential cross-contamination from the test rodlets that contain non-radioactive fission product dopant disks. NOTE: Refer to Section 6.3 for a description of test chamber and aerosol apparatus *decontamination* procedures used after (i.e., between) each test performance, to minimize subsequent cross-contamination. Testing with all Phase 3 test rodlets that contain no dopants has been performed first. Test turn-around or cycle time is dependent on the operational and test chamber decontamination schedule times, as well as other intervening factors.

Phase 4 tests, as listed in Table 3.4, will use radioactive spent fuel pellets in short test rodlets. Four of the Phase 4 tests will use high burnup (~ 72 GWd/MTU) spent fuel originating from the H.B. Robinson pressurized water reactor. Another four Phase 4 tests will use a low-medium burnup (~ 38 GWd/MTU) spent fuel originating from the Surry pressurized water reactor. All of the spent fuel is being characterized in detail and fabricated into test rodlets at Argonne National Laboratory. The Phase 4 explosive- aerosol testing will be conducted in the Gamma Irradiation Facility, GIF, at SNL starting in 2007. The final calculation of the spent fuel ratio, SFR, as a function of aerosol particle size ranges, will be based on a comparison of the aerosol particle results from the Phase 4, actual spent fuel data, to the Phase 3, surrogate DUO_2 data. These data will be obtained from paired sets of experiments using identical test conditions and apparatus.

Phase 4 test conduct and test turn-around or cycle time is dependent on the operational and facility schedule times, still to be finalized. Phase 4 test chamber will not be decontaminated post-test, since each Phase 4 test chamber will be used one-time only, then stored appropriately.

Table 3.4 Phase 4 Tests: Actual Spent Fuel Test Matrix

Test Phase 4: Actual Spent Fuel (PWR) Rodlets, from ANL			
Test #	Pressure ^	Variables	GIF Date *
4/1	~ 44 bar (rod plenum)	H.B. Robinson, high-burnup, ~72 GWd/MTU	2007
4/2	~ 44 (He)	Air (in aerosol chamber)	2007
4/3	~ 44	N_2	2007
4/4	~ 44	N_2	2007
4/5	~ 33 bar	Surry, low-med burnup, ~38 GWd/MTU	2008
4/6	~ 33 (He)	Air	2008
4/7	~ 33	N_2	2008
4/8	~ 33	N_2	2008

(^ modified to 1 bar He; refer to Section 8.4)
(* estimated schedule, based on GIF availability, subject to future revision)

4. TEST COMPONENT DETAILS, PHASE 2+

The major components required for conduct of the surrogate and spent fuel sabotage, explosive HEDD impact, and aerosol measurement tests include: test rodlets, consisting of target pellets, fission product dopants, and Zircaloy-4 cladding tube assemblies; a test chamber for collecting explosively particulated aerosol materials, with either a semi-open aerosol collection chamber or a vertical containment vessel with co-joined aerosol and explosive chambers; multiple aerosol particle collectors and associated sampling systems, instruments for temperature and pressure measurements; a conical shape charge (CSC), also known as the HEDD; a HEDD-jet stop assembly; and, test facilities to perform the tests within. These components shall be described individually.

Test components have been modified and upgraded as a function of time. Phase 2 Test components used during 2002 and 2003 were described in detail in [Molecke et al., 2004a] and those used during 2004 were described in [Molecke et al., 2005a]; they will not be repeated herein. Details on test components for Phase 2+ tests, tests 2/10A through 2/10F, the major activity performed in FY 2005, follow.

4.1 Surrogate Material Test Rodlets, Phase 2+

All Phase 2+ surrogate test rodlets consist of non-pressurized Zircaloy-4 cladding tubes containing either multiple pellets of cerium oxide ceramic pellets plus multiple fission product dopant disks or pellets of fission product doped (internally) cerium oxide pellets (tests 2/10A-2/10B or 2/10C-2/10D, respectively), or pellets of German high-activity / high-level waste (termed HAW in Europe, HLW in U.S.) glass pellets with internal dopants (tests 2/10E-2/10F). The pellets are held within the tube by adjacent steel end holder rods. Photographs of these test rodlets and end holder rods during assembly, and sample weights in grams, are shown in Figures 4.1, 4.2, and 4.3. In all these rodlets, the Zircaloy-4 cladding tube was 8.0 inches (203 mm) long, with a 10.6 mm outside diameter, a 9.32 mm inside diameter, and a wall thickness of 0.634 mm; other tube details are in [Molecke et al., 2005a], Section 4.1.2.

Test rodlets for tests 2/10G and 2/10H, to be performed by Fraunhofer Institut in Germany, in 2006, will be similar to the rodlet shown in Figure 4.2.

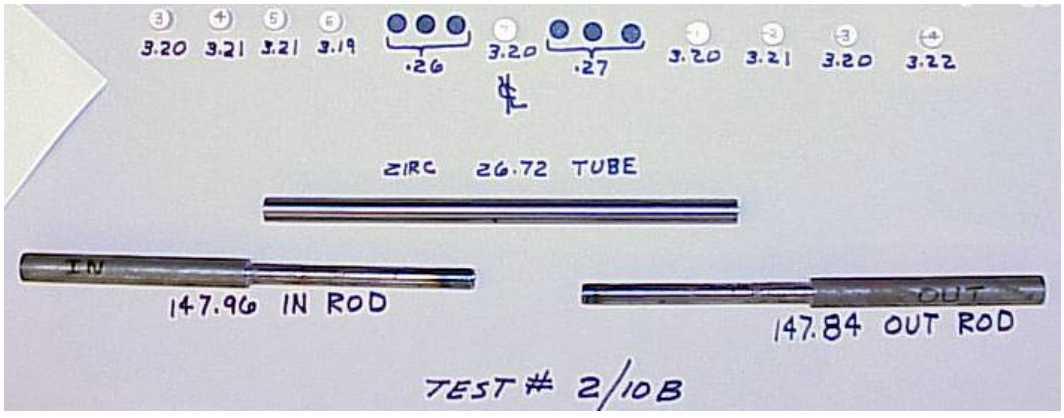


Figure 4.1 Phase 2+ Rodlet Test 2/10B, Pellets, Fission Product Disks, and Rod Holders

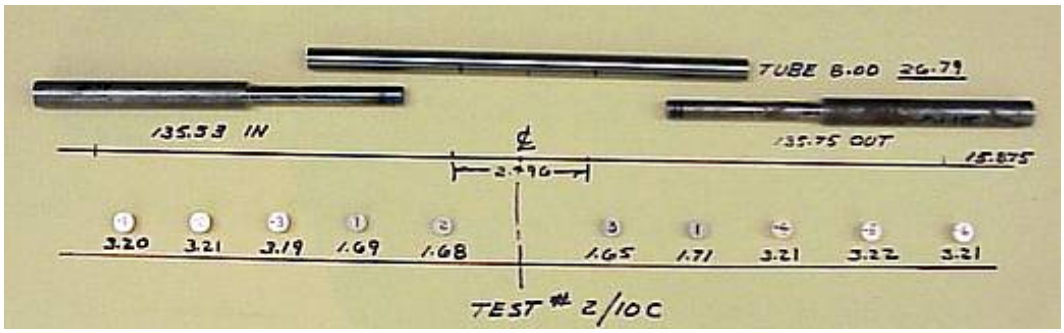


Figure 4.2 Phase 2+ Rodlet Test 2/10C, Pellets, Doped Pellets, and Rod Holders

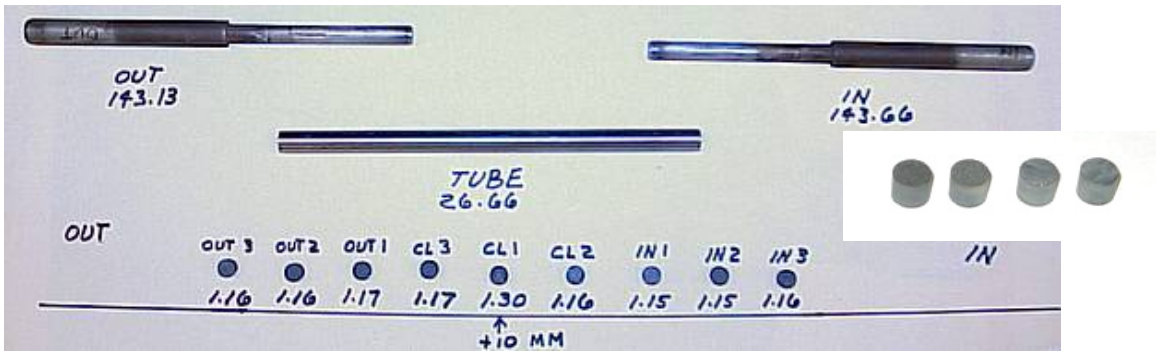


Figure 4.3 Phase 2+ Test 2/10F Rodlet, German Surrogate HLW Glass Doped Pellets

4.1.1 Surrogate Cerium Oxide Pellets

Cerium oxide powder has been pressed and sintered into ceramic pellets for our testing purposes, by the Ceramic Synthesis and Processing, Department 1815, at SNL. The cerium oxide powder (99.9 % pure, about 5 µm grain size) was mixed with about 3 wt. % organic material binder, mechanically screened, then uniaxially dry pressed in a 10.9 mm-diameter metal die (nominally at ~1900 Kg-force, 4200 pounds-force) into "green" pellets. These were fired at a rate of 3°C/minute to about 600 °C for 2 hours for binder burnout, then sintered at a rate of 5°C/minute to about 1600°C for 2 hours, followed by a cool-down at 5°C/minute to room temperature [Ewsuk, personal communication, 2005]. Measurements of apparent pellet porosity and Archimedes density were then performed. A theoretical cerium oxide density of ~ 92-95% was achieved. The pellets were made to fit snugly (i.e., with minimal pellet-to-cladding gap) into the Zircaloy 4 cladding tubes. Table 4.1 lists measured pellet specifications for all Phase 2+ pellets.

4.1.2 Fission Product-Doped Cerium Oxide Pellets and Dopant Disks

One of the major goals of this overall experimental program is to quantify the potential enrichment of volatile fission product nuclides on respirable-size particulates produced from a spent fuel–HEDD jet impact. The fission product species and their expected concentrations in actual PWR spent fuels were described previously, in [Molecke, et al., 2005a]. We also want to evaluate the effects, if significant, of the distribution homogeneity of the fission product dopant within the surrogate material pellet, whether located at discrete, localized positions within fission product dopant disks adjacent to cerium oxide pellets (as in previous Phase 2 tests), or distributed throughout the pellet.

Table 4.1 Cerium Oxide and HLW Glass Surrogate Pellet Specifications, as Fabricated

Test #	Pellet Wts. ave. & (total)	Ave. Theoretical Density	Average Diameter	Average Height (total)	Pellets/ per Rod	Dopants
2/10A	3.20 g (28.779 g)	95.3% 6.79 g/cc	9.08 mm	7.43 mm (66.9 mm)	9	include 6 dopant disks, 0.534 g total
2/10B	3.20 g (28.842 g)	94.4% 6.73 g/cc	9.12 mm	7.28 mm (65.5mm)	9	include 6 dopant disks, 0.524 g total
2/10C	3.20 g (19.187 g)	91.9% 6.56 g/cc	9.11 mm	7.49 mm (44.9 mm)	6	⬅ un-doped pellets
	1.63 g (6.516g)	78.7% 5.62 g/cc	8.75 mm	4.83 mm (19.3 mm)	4	⬅ internally doped CeO_2 pellets
2/10D	3.21 g (19.236 g)	95.1% 6.79 g/cc	9.13 mm	7.22 mm (43.3 mm)	6	⬅ un-doped pellets
	1.64 g (6.567g)	79.0% 5.64 g/cc	8.77 mm	4.83 mm (19.3 mm)	4	⬅ internally doped CeO_2 pellets
2/10E	1.15 g (10.35 g)	- - 2.58 g/cc	9 mm	7.0 mm (63 mm)	9	HAW/HLW glass, internal dopants
2/10F	1.17 g (10.53 g)	- - 2.58 g/cc c	9 mm	7.0 mm (63 mm)	9	HAW/HLW glass, internal dopants
2/10G (in 2006)	3.21 g (19.240 g)	95.2% 6.79 g/cc	9.13 mm	7.21 mm (43.3 mm)	6	⬅ un-doped pellets
	1.64 g (6.79g)	77.0% 5.50 g/cc	8.80 mm	4.91 mm (19.6 mm)	4	⬅ internally doped CeO_2 pellets
2/10H (in 2006)	3.21 g (19.250 g)	95.2% 6.78 g/cc	9.13 mm	7.22 mm (43.3 mm)	6	⬅ un-doped pellets
	1.64 g (6.576g)	75.5% 5.38 g/cc	8.84 mm	4.97 mm (19.9 mm)	4	⬅ internally doped CeO_2 pellets

For tests 2/10A and 2/10B, we used discrete, plastic resin-based fission product dopant disks, as described in Section 4.1.3 in [Molecke et al., 2005a]. However, the measured concentrations of fission product species sorbed onto respirable particles was very low in the past tests (2/5E, 2/5G, 2/6A, 2/6B, 2/8C, and 2/8D) that incorporated the two fission product disks (refer to Figure 4.4 in [Molecke et al., 2005a]). Therefore, we now incorporated six fission product dopant disks for these new tests. Three fission product dopant disks were located on either side of the central (of nine total) cerium oxide pellets; refer to Figure 4.1. The HEDD jet-disrupted (particulated) region in these test rodlets includes all of the central pellet, all six dopant disks, and essentially all of the adjacent two cerium oxide pellets. The total concentrations of each fission product chemical species in each Phase 2+ test rodlet are listed in Table 4.2.

In order to obtain cerium oxide ceramic pellets with the fission product dopants internally incorporated within the pellet matrix in an near-homogeneous manner, Sandia Ceramics personnel [Ewsuk, personnel communication, 2005] developed new doped pellet fabrication techniques. They developed a modified heat-treatment schedule to produce a lower sintered density (~80% relative density) CeO_2 pellet with continuous porosity, to allow for CsI (dopant) melt-infiltration in a subsequent heat treatment. The lower density pellets do not shrink as much as un-doped, higher density (~92-95% theoretical density) pure CeO_2 pellets. It is necessary to compensate for the lower shrinkage in pressing and to press a smaller diameter pellet in an existing die that will produce a sintered pellet that will fit within the Zircaloy cladding tube. Ceramics personnel deter-

mined that CsI, when heated above its melting temperature, can be physically infiltrated into the continuous porosity of the CeO_2 pellet. Particles of CsI were placed on top of a sintered ~80% relative density CeO_2 pellet and heated in air to ~ 675°C. The CsI on top of pellet disappeared after the heat treatment, and the pellet weight increased, indicating that the CsI melted and physically infiltrated the porous CeO_2 pellet.

Eventually, granulated CeO_2 powder was hand mixed together with the other fission product dopants including Ru (metal powder, instead of previously used ruthenium oxide), plus non-volatile SrO and Eu_2O_3. The powder mix was uniaxially dry pressed in a 9.8 mm-diameter die, then sintered. As anticipated, the addition of the dopants to the CeO_2 retarded densification and reduced shrinkage during sintering. To produce a higher sintered density ceramic pellet, a CeO_2 plus dopant pressed pellet was sintered in air by heating at 3°C/min to 600°C for binder burnout, holding 2 hrs, heating at 5°C/min to 1400°C, holding 2hrs, and cooling at 5°C/min to room temperature. Sintering produced an intact ceramic body with a theoretical density of ~75-80%. The resultant pellets were subsequently melt-infiltrated with the CsI at ~ 675°C to produce the final doped pellets. Scanning electron microscopy (SEM) and energy dispersive x-ray spectroscopy (EDS) were used to verify the post-infiltration distribution of CsI; it infiltrated about 1/3 – 1/2 of the way into the pellet, not uniformly. To increase the homogeneity of the melt-infiltrated CsI, the final pellets were made about 5 mm high, rather than the un-doped pellets of 7.2-7.5 mm height.

In order to keep the total length of the pellet stack (un-doped plus doped CeO_2 pellets) similar, test rodlets 2/10C and 2/10D (as well as future tests 2/10G and 2/10H) incorporate a total of four doped pellets in the central rodlet stack, surrounded by three un-doped pellets at either end; refer to Figure 4.2. A photograph of the un-doped and fission product doped pellet stack is shown in Figure 4.4. The (~20 mm-length of) fission product-doped pellets at the center are (or will be) totally particulated by the HEDD jet during the test. Specific details on the fission product doped CeO_2 pellets are listed in Table 4.1.

The total concentrations of each fission product dopant per each Phase 2+ test rodlet was planned to be about triple that used in earlier Phase 2 tests. The analyzed / calculated concentrations are listed in Table 4.2. The fission product cesium iodide content was measured directly by weight gain after the melt-infiltration process. The other dopant species concentrations in the doped CeO2 pellets are based on chemical analysis of two similar pellets first dissolved/digested by a lithium metal/lithium tetraborate fusion procedure, then analyzed by inductively coupled plasma-mass spectroscopy, ICP-MS. The analyzed concentrations of ruthenium are, unfortunately, much lower than planned. The ruthenium metal incorporated into the pellet matrix presumably converted to ruthenium oxide during the sintering process, and much of it migrated to the outer surfaces of the pellet and thermally volatilized. This is evident by observing the black outer surface of the doped pellets, at center in Figure 4.4.

Figure 4.4 Phase 2+ Un-doped and Fission Product-Doped Cerium Oxide Pellets

Table 4.2 Fission Product Dopant Chemicals, per Phase 2+ Test

Phase 2 Test #	Cesium Iodide, CsI	Ruthenium, as RuO_2	Strontium Oxide, SrO	Europium Oxide Eu_2O_3	Shape Factor & Weight
	Actual (calculated) dopant weights, post-sintering				
2/10A	**101** mg	**18.8** mg	**14.6** mg	**15.2** mg	6 disks (0.534 g)
2/10B	**98.7** mg	**18.5** mg	**14.3** mg	**14.9** mg	6 disks (0.524g)
2/10C	**204** mg	**0.47** mg	**30** mg	**75** mg	4 pellets
2/10D	**260** mg	**0.47** mg	**30** mg	**75** mg	4 pellets
2/10E	**49** mg **(as Cs_2O)**	**31** mg **(MnO_2)**	**188** mg **(La_2O_3)**	**107** mg **(Nd_2O_3)**	9 **glass** (10.35 g)
2/10F	**49** mg **(as Cs_2O)**	**32** mg **(MnO_2)**	**192** mg **(La_2O_3)**	**108** mg **(Nd_2O_3)**	9 **glass** (10.53 g)
2/10G	**261** mg	**0.47** mg	**30** mg	**75** mg	4 pellets
2/10H	**270** mg	**0.47** mg	**30** mg	**75**mg	4 pellets

(Note: concentrations estimated as ± 10% for CsI, SrO, and Eu_2O_3; ± 50% for RuO_2)

4.1.3 Surrogate German HAW/HLW Glass Pellets

Fraunhofer ITEM and GRS provided Sandia with surrogate HAW (HLW) glass pellets for cooperative testing, in Phase 2+ tests 2/10E and 2/10F. These glass pellets were core-drilled out of a bulk glass sample originally fabricated at the Karlsruhe Nuclear Research Center in Germany. The glass composition is essentially identical to the HAW glass rodlets used in earlier tests 2/7A and 2/7B [Molecke et al., 2004a] during FY 2004. The vitrified glass matrix was composed of about 84 wt. % SiO_2, MgO, MnO_2, CaO, Na_2O and other glass frit material. The remaining 16 wt. % contained dopants, primarily thermally volatile Cs_2O (0.47 wt. %, melting point 490°C) and MnO_2 (0.30 wt. %, melting point 535°C), plus nonvolatile La_2O_3 (1.82 wt. %) and Nd_2O_3 (1.03 wt. %), plus copper and iron. It is presumed that the cesium dopant was retained and not volatilized in the (molten, during fabrication) glass material in silicate compounds [Peacock et al., 2002], and is homogeneously distributed in each pellet. Specifications on these HAW/HLW glass pellets are listed in Table 4.1. Calculated dopant concentrations are listed in Table 4.2.

4.2 Aerosol Collection/ Explosive Test Chamber System, Phase 2+

A new aerosol collection test chamber was specifically designed and fabricated for use in the Phase 2+ series of tests, and is shown in Figure 4.5. It is intended to be intermediate in design between the semi-open, "square box" aerosol collection chamber used in the earlier Phase 2/4 series of tests, refer to [Molecke et al., 2004a], and the top, cylindrical half (only) of the Phase 3 "Tweety Bird" aerosol-explosive test apparatus, shown in Figure 5.4. The Phase 2+ test chamber is similar in construction to, and has the same internal volume as the Phase 3 aerosol top chamber, with the same four internal aerosol sampling tubes (sampling from the test rodlet area) and the same four independent sets of Marple impactor and large particle separator systems. The test rodlet is also positioned and installed horizontally, as shown in Figure 4.6. The HEDD or CSC (conical shaped charge) is located externally, on the side of the test chamber (left side in Figure 4.5, below the fragment deflector, but not installed yet), and fires horizontally through a 1 inch-diameter (2.5 cm) hole. The HEDD-jet stop block assembly is also horizontal and located on the outside of the cylinder, shown at right side in Figure 4.5, but connected to it; internal components are re-

placed after each test. The test chamber will be "open" for only about one second after detonation and then is sealed by an internal, fast-acting gate isolation valve, visible in Figure 4.6. This internal valve is opened at -4 seconds prior to CSC detonation, and then closed at +1 seconds following detonation. We expected somewhat lower internal temperatures and somewhat less soot contamination in the "semi-open" Phase 2+ chamber compared with the sealed system in the Phase 3 aerosol-explosive system. The Phase 2+ test chamber has a removable, bolted-on top lid that allows for access to the inside for post-test particulate debris removal and decontamination.

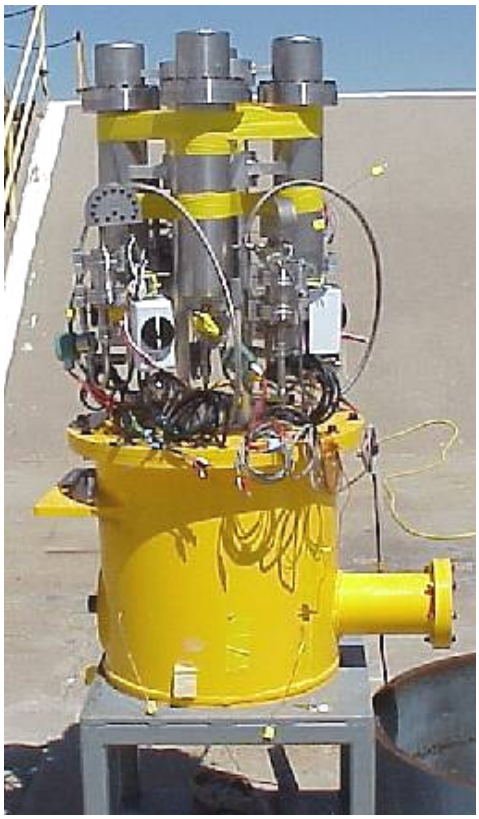


Figure 4.6 Phase 2+ Chamber Interior, showing Rodlet, Closure Valve, Thermocouples

Figure 4.5 Phase 2+ Test Chamber and Aerosol Apparatus

4.3 Other Phase 2+ Test Components

Aerosol Particle Sampling Systems: We used four, redundant aerosol particle sampling systems for the Phase 2+ tests, essentially identical to those used and described in Section 4.3 of [Molecke et al, 2005a] for the preceding Phase 2 tests. Each independent sampling system includes a: Marple particle impactor (Model 298), with an external containment enclosure that was designed, fabricated, and installed onto the impactor housing to provide a leak-proof double containment; a large particle samplers (LPS), designed by both SNL and Fraunhofer ITEM personnel, and fabricated by SNL; plus, associated sampling tubes, a primary ball-type valve (with a 3/8 inch, 0.95 cm inner diameter) which provide isolation from the initial pressure pulse from the explosive charge, a secondary ASCO (model 8262G220) normally closed solenoid valve, critical orifice that is connected to the outlet of the impactor, an in-line HEPA filter, and vacuum bottle, visible in Figure 4.5. The sampling flow rate is measured with a Gilibrator Primary Flow Calibrator, Model # D-800268; the sampling flowrate is nominally set at 2 Lpm. Each particle sampling system is independently removable from the top of the test chamber, while the aerosol test chamber (below) remains sealed with use of individual manual-closure valves.

Prior to test sampling, fiberglass collection substrates and back-up filters are weighed, recorded and placed in the impactor. After sampling, the substrates and filter are re-weighed; the weight increase on each substrate is the mass of particles in the impactor-stage size range. The total weight of particles on all stages and filter is added and the percent particle mass in each size range is calculated. Respirable particle mass fraction is determined from the particle size distribution.

The inside of the LPS component is shown in Figure 4.7; the top cover of the LPS component is shown in Figure 4.8. The fiberglass strip substrate visible within the center groove in Figure 4.7 samples aerosol particles between about 30 to 100 μm AED. This strip is removed post-test, and cut into four segments (each weighed) for subsequent acid dissolution and chemical elemental analyses using inductively coupled plasma-mass spectrometry (ICP-MS). Chemical analyses are necessary because much of the collected particle mass consists of fine carbon soot, a combustion byproduct of the HEDD detonation.

Figure 4.7 Inside of LPS Component

Figure 4.8 Top Cover of LPS Component

Instrumentation: Multiple pressure and temperature instrumentation were used in the Phase 2+ tests, including fourteen thermocouples and five pressure transducers. The instrumentation was purchased from Omega. The thermocouples used were Omega Type K fast-response type and the pressure transducers are 100 psi (690 kPa), manufactured by Endevco Inc., Model 8530B-100. Instrumentation data were logged into an electronic data acquisition instrument. Figure 4.9 shows a schematic of the Phase 2+ test chamber thermocouple locations and the aerosol system layout.

Twelve of the thermocouples are installed within the test aerosol chamber (refer to Figure 4.9 and to Table 4.3). Four of these thermocouples (#1-#4) were installed through holes drilled in the lower wall portion of the test chamber and located at the entrance of each of the Impactor sample tubes. Eight more (#5-#12) through holes drilled in the top of the chamber lid and located about 6 inch (15 cm) down from the inner wall of the chamber lid; two thermocouples each were run down the impactor sample tubes, at 180 degrees from each other. Two more thermocouples (#13 and 14) were installed above the aerosol chamber, within the particle sampling tubes on the down-stream side of the Large Particle Separators. The pressure transducers are located one each on the downstream side of the Large Particle Separators and one on the inside lower part of the test chamber.

Conical Shape Charge (CSC): The HEDD, as described in [Molecke et al., 2005a], is identical to those used in all prior Phase 2 tests, and to be used in forthcoming Phase 3 and Phase 4 tests. The CSC is held in place in the test chamber with a polyvinyl chloride (PVC) fixture-holder. The

CSC and its holder are replaced for each succeeding test. The CSC is located with the same optimized, final stand-off distance used for all other Phase 2 and Phase 3 tests, 7.5 inches (19 cm).

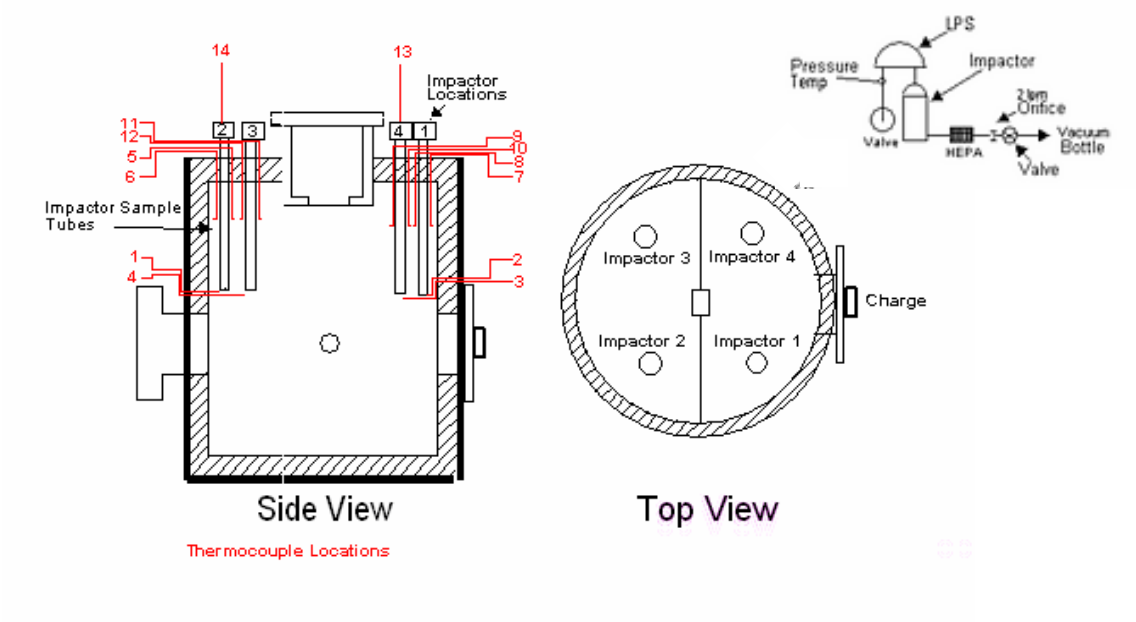


Figure 4.9 Schematic of Phase 2+ Test Chamber Instrumentation and Aerosol System

Table 4.3 Phase 2+ Thermocouple Sample Locations

1. Located at Impactor # 2 sample tube inlet
2. Located at Impactor # 1 sample tube inlet
3. Located at Impactor # 4 sample tube inlet
4. Located at Impactor # 3 sample tube inlet
5. Located on Impactor # 2 sample tube, 6" from bottom of chamber lid
6. Located on Impactor # 2 sample tube180 from 5, 6" from bottom of chamber lid
7. Located on Impactor # 1 sample tube, 6" from bottom of chamber lid
8. Located on Impactor # 1 sample tube180 from 5, 6" from bottom of chamber lid
9. Located on Impactor # 4 sample tube, 6" from bottom of chamber lid
10. Located on Impactor # 4 sample tube180 from 5, 6" from bottom of chamber lid
11. Located on Impactor # 3 sample tube, 6" from bottom of chamber lid
12. Located on Impactor # 3 sample tube180 from 5, 6" from bottom of chamber lid
13. Located on Impactor # 4 LPS co-located with pressure transducer
14. Located on Impactor # 2 LPS co-located with pressure transducer

Test Facilities: All Phase 2+ tests to date have been performed outside of the remote-site SNL building 6750, located at the Gun Site/ Terminal Ballistics Facility. This remote site is part of the Sandia Explosives Technology Group.

5. PHASE 3 and 4 TEST COMPONENTS

Significant effort was also expended during FY 2005 in preparing for and initiating Phase 3 tests using slightly radioactive, depleted uranium oxide, DUO_2, test rodlets, and continuing the planning for Phase 4 spent fuel tests. The first three Phase 3 tests were successfully performed during the first half of FY 2006. In this section we shall provide descriptions of the primary test components, the test rodlets and the aerosol-explosive test chamber, and the test facility used, the Sandia Explosive Components Facility, Building 905, explosives test room 1213A, along with the associated safety and radiological control constraints.

5.1 Phase 3 Depleted Uranium Oxide Test Rodlets

Six, unirradiated, depleted uranium oxide pellet test rodlets are used for Phase 3 testing. The specific variables (internal rodlet atmosphere: air or 40 bar (4 MPa) helium within the end plenum regions of the rodlet, to simulate the approximate pressures found within spent fuel rods), inclusion of fission product dopant disks (no or yes), and aerosol test chamber atmosphere (air or nitrogen) for each rodlet were listed in Table 3.3. As part of the WGSTSC program cooperative efforts, all six of these test rodlets have been fabricated by CERCA (a Framatome-ANP, AREVA subsidiary), in Romans-Sur-Isère, France, for IRSN, for testing at SNL. Fabrication in, and shipment from, France was completed in July 2004; these rodlets were successfully received at SNL in August 2004. The French designation for the rodlet for test 3/1 is DUR-1, for 3/2 it is DUR-2, for 3/3 it is DUR-3, for 3/4 it is DUR-4, for 3/5 it is DUR-5, and for test 3/6 it is DUR-6. A photograph of all six Phase 3 test rodlets is shown in Figure 5.1. There is also an external center mark on the cladding for each rodlet, locating the center of the internal central pellet. The center mark is used for HEDD jet alignment purposes; these marks are (barely) visible in Figure 5.1.

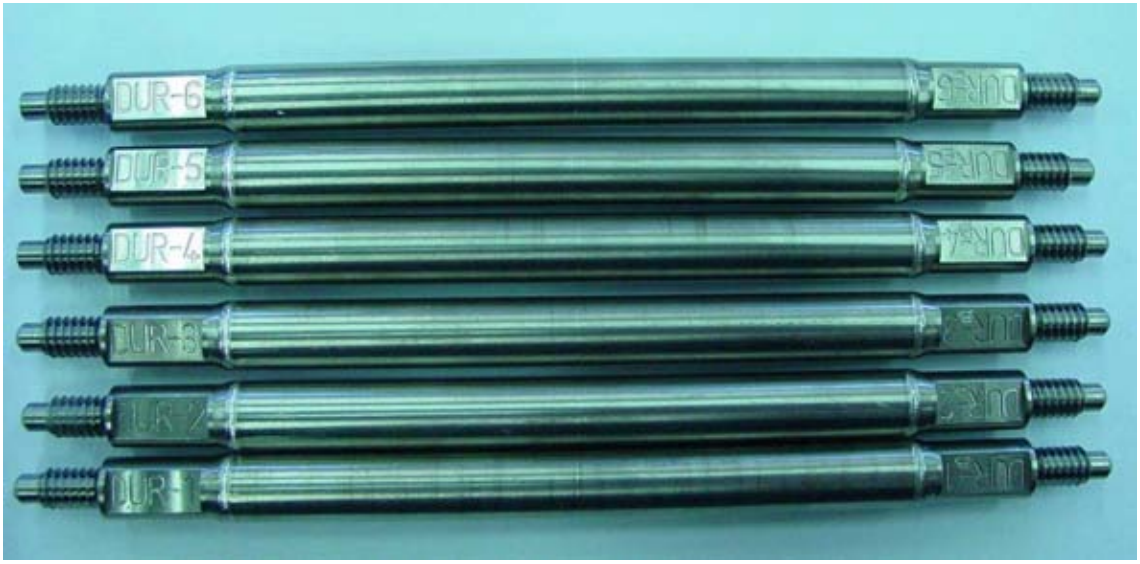


Figure 5.1 Photograph of Phase 3 DUO_2 Test Rodlets

The test rodlet design, particularly the end pieces, was a collaborative effort by IRSN, SNL, and Argonne National Laboratory, and is shown schematically in Figure 5.2. The rodlet dimensions, except for total length, are very similar to the U.S.-origin pressurized water reactor, PWR, fuel pins. The rodlets are fabricated from Zircaloy 4 cladding tube of 10.6 mm outside diameter, 9.32 mm inside diameter, supplied to IRSN by SNL. The actual weights and dimensions for each test rodlet are listed in Table 5.1.

Table 5.1 Phase 3 DUO_2 Rodlet Specifications, as Fabricated

Rodlet # Test #	Rodlet Length	Rodlet Weight	Pellet Wts. ave. & (total)	Pellets per Rod	Variables	Dopants
DUR-2 3/2 **(A)**	166.05 mm	86.75g	9.601 g (48.003 g)	5	1 bar	none
DUR-5 3/5 **(B)**	166.00 mm	86.759 g	9.586 g (47.930 g)	5	40 bar He internal	none
DUR-1 3/1 **(C)**	167.93 mm			5	1 bar	2 dopant disks
DUR-3 3/3 **(D)**	167.89 mm			5	1 bar N_2 in chamber	2 dopant disks
DUR-4 3/4 (**E**)	167.95 mm			5	40 bar He internal	2 dopant disks
DUR-6 3/6 (F)	168.05 mm			5	40 bar He N_2 in chamber	2 dopant disks

CERCA fabricated the threaded end cap fittings (nine with no hole/ on left side of Figure 5.1, and three with a gas-filling hole, shown on the right side of Figure 5.2, for pressurization with helium gas followed by laser weld sealing), with machined plenum regions, from Zircaloy 4 bar stock. Test rodlet extension holders that screw onto the threaded ends of these test rodlets were fabricated at SNL. The test rodlets with end extensions are self-aligning when inserted horizontally into the Phase 3 test chamber, Figure 5.4.

The DUO_2 pellets used contain 0.2 wt. % of ^{235}U and were obtained from FBFC International (an AREVA subsidiary), in Dessel, Belgium. Each test rodlet contains five ~ 13.9 mm-long pellets of ~ 97% theoretical density DUO_2, with dished ends, as shown in Figure 5.2. The mean dimensions and specifications for each of the 30 DUO_2 pellets used are as follows:

Length = 13.945 mm; Diameter = 9.132 mm; Dish depth = 0.33 mm;
Weight = 9.597 g; density = 10.639 g/cc; theoretical density = 97.073 %.

On average, each of the six DUO_2 test rodlets contains 47.99 g of uranium oxide (ceramic), 42.33 g of uranium, including 0.085 g of ^{235}U. The calculated radiation content/activity is 21μCi/rodlet or 0.78 MBq/rodlet (specified as 4.699 MBq/all 30 pellets, and 1 MBq = 27 μCi). In addition to specifications and photographs, the DUO_2 rodlets were accompanied with the appropriate quality control documentation from CERCA and IRSN, the Certificate of Conformity, including: material supply sheets for pellets, cladding, and end caps; drawings; a list of fabrication and control operations; inspection data sheets for rodlets, helium testing, x-ray, and visual inspections; deviation notices; and final certificate of acceptance.

Four of the rodlets (DUR-1, 3, 4, and -6) also contain two of the non-radioactive fission product dopant disks (as used in the Phase 2 tests, provided by SNL; refer to Section 4.1.3) surrounding the central DUO_2 pellet, shown in Figure 5.2 and Figure 5.3. For each of these test rodlets, the actual weights of each dopant chemical, based on the measured dopant weights for two disks are:
CsI = 33.9 mg; RuO_2 = 6.4 mg; SrO = 4.9 mg; and, Eu_2O_3 = 5.2 mg (± 20%, estimated).

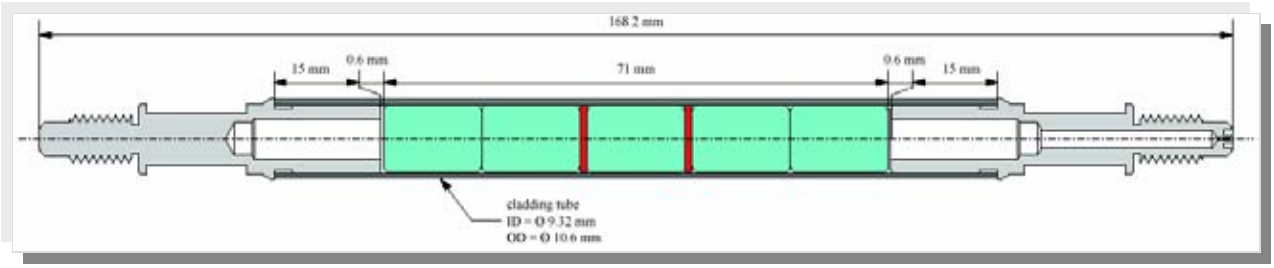


Figure 5.2 Schematic of Phase 3 DUO_2 Test Rodlet, DUR-4

Figure 5.3 DUO_2 Pellets and Dopant Disks for Test 3/1

Post-test disposal: Issues associated with the post-test disposal of the French-origin, unirradiated DUO_2 (residual) materials have been addressed at Sandia and previously resolved [Blejwas, 2003]. "Post-test depleted uranium-contaminated hardware and samples generated during … Phase 3 testing will be managed as low-level radioactive waste in accordance with the Sandia ES&H Manual. Representatives of the test program will prepare the appropriate documentation and submit the waste to the SNL Radioactive Waste and Nuclear Material Disposition Department. This waste will then be eligible for disposal at the Nevada Test Site as part of Sandia waste stream ALSA000000011. The Radioactive Waste and Nuclear Material Disposition Department will be responsible for transportation to the Nevada Test Site for final disposal." Note that the post-test DUO_2 (residual) waste materials are not "mixed waste" or "hazardous waste." No organic components or residual explosive compounds are present; the only post-detonation explosive residue of importance is carbon soot (particles).

5.2 Phase 3 Test Chamber

The aerosol-explosive test chamber to be used for all Phase 3 tests, as well as for the Phase 2 / Phase 3 cross-over tests [Molecke et al., 2005a], is shown in Figure 5.4, and has been engineered for total HEDD blast containment (pressure, fragmentation) and for total, leak-tight isolation of all particles produced. The Phase 3 test chamber is based on the earlier, less refined Phase 2 vertical aerosol-explosive test chamber (informally referred to as "Grandma") described in [Molecke et al., 2005a]. This Phase 3 chamber incorporates recessed, removable flange covers for the top aerosol and bottom explosive chambers. It weighs 999 kg (2202 lbs.), without aerosol apparatus attached, and has a total interior volume of 183 L. The main body of this test chamber is approximately 22 inches in diameter (56 cm) by 52 inches high (1.32 m), and is fabricated out of SA-516 Grade 70 carbon steel. The two flange cover plates are fabricated with 304 stainless steel. This test chamber was fabricated by PVC Co. (Precision Vacuum Components, a subsidiary of Accurate Machine and Tool), 2646 Baylor Dr. NE, Albuquerque, NM.

This test chamber is quality controlled *in accordance with* the American Society of Mechanical Engineers (ASME) code for pressure vessels, Section VIII Division 1, with internal SNL documentation [Dickey, 2004; Hagan and Dickey, 2004]. It was explosively over-tested successfully to twice the HEDD-produced pressures expected in planned usage (peak reflected blast pressure of ~ 800 psi, 55 bar, measured). This chamber has also been modeled for static stress analyses, welds have been 100% X-rayed in *accordance* with ASME code and dye-penetrant tested, and it has been hydrostatically leak tested [Dickey, 2004]. SNL explosive safety personnel have concurred that this "chamber (both the Phase 3 and following Phase 4 chamber iteration) is qualified for production testing and meets the requirements for a hazard classification and storage compatibility Group of 1.4S."

Figure 5.4 Phase 3 Test Chamber and Aerosol Sampling Systems

Aerosol Particle Sampling Systems: We use four, redundant aerosol particle sampling systems for the Phase 3 tests; these are identical to that used for the Phase 2+ tests, and were described in Section 4.3 and are visible in Figure 5.4. Each particle sampling system is independently remov-

able from the top of the test chamber, while the aerosol test chamber (below) remains sealed with use of individual manual-closure valves, preventing the release of radioactive particulates within.

Prior to sampling, the fiberglass collection substrates (or quartz fiber or Mylar, used in later tests to minimize substrate impurities) and back-up filters are weighed, recorded and placed into the impactors. The sampling flow rate through each system is controlled with a critical orifice which is connected to the outlet end of the impactor. The sampler flow rate is measured with a Gilibrator Primary Flow Calibrator, Model # D-800268. The sampling flow rate was set nominally at 2 Lpm and maintained with a critical orifice flow-meter. Actual flow rates are listed in Table 6.1. The particle sampling impactors are assembled, then leak checked and pressurized to ~ 30 psig (2 bar) and the sub-system pressures monitored with a pressure transducer and portable data acquisition system for approximately 24 hours. (For leak-check overtest purposes, the Marple impactor assemblies have been successfully pressure tested to ~80 psig, 5.5 bar). The flow is then measured for each impactor system and logged. For post-test sampling, the substrates and filter are removed then weighed inside of a portable glove box assembly; refer to Section 6.3.

5.3 Phase 3 Test Facility and Test Controls at SNL ECF

Originally [Molecke et al., 2005a], all Phase 3 DUO_2 and Phase 4 spent fuel aerosol-explosive tests were to be performed at the Sandia Gamma Irradiation Facility (GIF), Test Cell 3, using closely controlled radiological and explosive safety conditions, under both SNL and DOE-Sandia Site Office (SSO) authorizations. However, due to appreciable delays experienced in FY 2005 for receiving final approval for the GIF Documented Safety Analysis (DSA) from the SSO, performance of the Phase 3 test program at an alternate facility at Sandia was opened to consideration.

In May 2005, a joint meeting was conducted with SNL Explosive Components, Materials Transportation Testing and Analysis, Aerosol Science, Environmental Safety, Industrial Hygiene, and Radiation Control technical and management personnel to discuss the possibility of moving the performance of Phase 3 testing with DUO_2 target rodlets to the SNL Explosive Components Facility (ECF), Bldg 905. This move would have a significant positive impact on test schedule and expense, compared to using the GIF, specifically to minimize schedule delays. The level of explosive safety and radiological containment would need to be essentially the same in either the GIF or the ECF facilities. The ECF building had not been used previously for radioactive testing of this type or scope nor was it classified as a nuclear facility.

It was concluded that this test move was indeed feasible and could be accomplished with the following requirements and test control issues met: (a) need approved documentation of a NEPA amendment for moving the Phase 3 tests from GIF to ECF; (b) need a PHS/HA (Preliminary Hazard Screening/ Hazard Assessment) review and approval; (c) need the development and approval of a formal Operating Procedure (OP) for the test performance, with the use of properly trained personnel; (d) need to arrange for appropriate waste management for the post-test DUO_2 materials, including decontamination between tests; and, (e) need to include appropriate secondary containment of the test chamber within the ECF, to address potential release of particulate radioactive materials.

These control issue requirements were successfully satisfied, as follows:

(a) A revised NEPA Amendment, SNA05-0313, "Surrogate/Spent Fuel Sabotage Aerosol Ratio Testing, Phase 3: Addendum to SNA04-0308," was prepared and approved on June 13, 2005. [NEPA SNA05-0313, 2005] The prior NEPA documentation, SNA04-0308, was specific to radioactive aerosol-explosive testing in the GIF, in Sandia Tech Area V. The

revised NEPA Amendment, SNA05-0313 is specific to the DUO_2 testing, only, in ECF Building 905, test firing pad Room 1213/1213A. The NEPA amendment and its predecessors was reviewed and received a determination from DOE SSO of CXB3.6, Siting/ construction/ operation/ decommissioning of facilities for bench-scale research, conventional laboratory operations, small-scale research and development and pilot projects.

(b) A PHS/HA (Preliminary Hazard Screening/ Hazard Assessment) for Phase 3 Surrogate Spent Fuel Testing [PHS SNL05A01146-001, 2005], was prepared, reviewed, and approved on July 19, 2005. This test project was determined to have a "Hazard Classification" of Low.

(c) An environmental safety and health formal SNL internal Operating Procedure (OP) [ETG-OP-DETEVAL-109-A, 2005], Phase 3: Surrogate Spent Fuel Sabotage Explosive-Aerosol Testing, Mechanical Set-Up and Explosives Procedures, was developed, and approved by Sandia Explosive Projects and Diagnostics personnel for control of all Phase 3 tests at the Sandia ECF. This operational procedure also includes major contributions from aerosol and radiation control personnel involved in the test program. Several appropriate Radiological Work Permit (RWP) requests were written to mate with the OP, and approved. The OP internal document provides instructions and guidance for the safe operation of the entire test performance including sections on: Phase 3 test description, ownership information, global safety procedures, specific hazards, training requirements, personnel protective equipment, detailed explosives and mechanical procedures and procedure checklists, plus attachments on aerosol equipment set-up, preparation, installation, and sample recovery, plus decontamination protocols. A "dry run" review of the Operational Procedure and associated RWPs is conducted the day before each actual test, to ensure that all mechanical, aerosol, and instrumentation systems are working as planned.

(d) Appropriate waste management controls for the post-test DUO_2 materials are described in the PHS/HA document [PHS SNL05A01146-001, 2005]. The post-test wastes are considered low-level contaminated depleted uranium oxide. There are no mixed wastes or hazardous waste materials generated. All explosive material is entirely consumed during testing, only residual carbon soot (plus some water vapor) remains.

(e) Secondary containment. The primary barrier to the release of particulate radioactive materials during and after the Phase 3 DUO_2 tests is the vertical explosive-aerosol test chamber, as described in section 5.2. To further control the *potential* release of particulate radioactive materials within the ECF, secondary barriers have been implemented. The test chamber is located within a Large Walk-in (blast enclosure) Chamber in room 1213A; this is illustrated in Figure 6.17, in Section 6.3. The Large Walk-in Chamber floor and instrumentation ports will be lined with plastic and other material as an additional secondary containment barrier. Furthermore, inside the walk-in chamber is a large portable plastic containment tent, supported by a metal frame about 12 ft-long x 7 ft-wide x 7.5 ft-high (3.6x2.1x2.3 m). The secondary containment tent will serve as the barrier for the radiological contamination area and will be sealed during the test and all post test decontamination activities. Access to the primary aerosol-explosive Phase 3 test chamber during the explosive portion of the test will be controlled by the closing and locking of the Large Walk-in Chamber access door via seven hydraulic pins into the Chamber door. The door will be interlocked to the monitoring and firing system.

(f) Post-test, the aerosol apparatus systems are disassembled and weight of all aerosol samples are obtained in an external (directly outside the Large Walk-in Chamber) small plastic glove-box enclosure within room 1213A. The secondary containment physical controls are accompanied by radiological protection surveys performed by radiological control techni-

cians. All post test work, either in the glove box or containment tent, is supported by radiological control technicians under the direction of the current radiological work permits.

5.4 Phase 4 Test Chambers and Spent Fuel Rodlet Status

Phase 4 Test Chambers: The aerosol-explosive, vertical test chambers for the Phase 4 spent fuel tests have been designed and two were fabricated by PVC Co. and delivered to SNL in FY 2005. These Phase 4 test chambers are very similar to the Phase 3 test chamber, except that they have no flanged access port to the top aerosol collection chamber. Once a Phase 4 chamber is used for a spent fuel explosive-aerosol test, it is never opened, to prevent potential release of spent fuel aerosol particles contained inside. The Phase 4 test assembly during fabrication consists of two pieces, top and bottom, that are welded together into a single test chamber assembly prior to delivery. The top piece is designated as "high pressure or vacuum flange, open end (the aerosol chamber)," and the bottom piece is termed the "high pressure or vacuum flange closed end (the explosive containment chamber)." The remaining six of eight Phase 4 aerosol-explosive test chambers will be fabricated in FY 2007, as required.

Both Phase 3 and Phase 4 test chambers have a top head plate that is 5 inches, 12.7 cm, thick, nominally for radiation shielding. The total internal volume of the Phase 4 aerosol chamber is identical to the Phase 3 aerosol chamber; compensation has been made for the volume loss from the lack of an internal flange support in the Phase 4 top chamber. The two fabricated Phase 4 test chambers are both in storage at the Sandia Explosive Component Facility until needed. They have been purged and backfilled with dry nitrogen gas, then sealed, to minimize potential internal corrosion during storage.

The Phase 3 and Phase 4 test chambers have a top-mounted, internal (not visible in Figure 5.4), HEDD-jet stop block. The internal components of this stop block consist of alternating plates of mild steel and polypropylene, each 1.2 cm-thick. The purpose of these plates is to stop the very energetic HEDD jet, as well as the less energetic residual metallic slug or "carrot," within a manageable distance; this distance is appreciably less than 30 cm. The bottom-most plate (hit first by the HEDD jet) is made of steel. The polypropylene plates are critical for keeping this stopping distance to a minimum length. Multiple stop plates are replaced after each Phase 3 test (but not for Phase 4 tests).

Each Phase 4 test chamber will be used *one time only*, and then temporarily stored at Sandia in the GIF floor vault, with the explosively-disrupted, post-test spent fuel rodlet and residual particulates contained within. At a later date, each sealed, post-test Phase 4 chamber, probably enclosed within an overpack (yet to be designed) will be shipped off-site within a GE-2000 transport cask to an approved, limited-term radioactive material (temporary) storage facility (tentatively at the Idaho National Laboratory) prior to final disposal, when a licensed facility (presumably Yucca Mountain repository) is available to accept these chambers.

Phase 4 Spent Fuel Test Rodlets: The Phase 4 spent fuel pellets/rods, both from the high-burnup H.B. Robinson reactor and the lower-burnup Surry reactor, have been fully characterized in the Argonne National Laboratory Alpha Gamma Hot Cell (AGHC) facility. Characterizations include: visual exams, axial gamma scanning, optical metallography, cladding hydrogen content, and isotopic analyses – for following aerosol and radiological source term material behavior evaluations. The Spent Fuel Characterization Report, ANL-05/41 [Burtseva, Tsai, and Billone, 2005] has been finalized and was delivered to SNL in November 2005. A second, Surry isotopic analysis report is in progress.

SNL has requested Argonne National Laboratory to delay the completion of test rodlet fabrication activities until FY 2007, because Sandia cannot accept delivery until a DOE approved agreement is made for interim, off-site storage of the test chambers. Argonne will complete fabrication of the spent fuel rodlets, including post-welding leak testing and external contamination control, and then transport the rodlets to SNL for testing when Sandia has received DOE authorization to accept them. Following preparation and approval of an Argonne transportation plan, Argonne intends to ship all eight test rodlets within a GE-100 transport cask. Once accepted at SNL, these spent fuel rodlets will be stored at the GIF until each one is used individually in the Phase 4 experiments.

NOTE: Refer to Section 8.4 for the WGSTSC partners agreement to accept the fabrication and use of *non-pressurized* Phase 4 spent fuel test rodlets.

6. TEST CONDUCT AND AVAILABLE RESULTS

A total of ten explosive-aerosol tests were performed during the time period of November 2004 through March 2006. This includes one Phase 2/Phase 3 cross-over test, 2/9C, six Phase 2+ tests for enhanced fission product sorption evaluations in a surrogate cerium oxide or German HAW/HLW glass rodlet system, tests 2/10A through 2/10F, and three Phase 3 depleted uranium oxide tests, 3/2 (A), 3/5 (B), and 3/1 (C). Test 2/9C and all of the Phase 3 tests were performed in the same vertical explosive-aerosol test chamber, shown in Figure 5.4. All of the Phase 2+ tests were performed in a new, smaller aerosol test chamber, as shown in Figure 4.5, with external conical shaped charge detonation. The aerosol sampling system used for all of these tests was essentially identical, consisting of four redundant Marple impactor plus Large Particle Separator (LPS) sampling assemblies. We will describe details for each of the tests, provide results and observations, pictures, data, and analyses of all available aerosol and instrumentation results to date.

Relevant aerosol particle sampling information for all of these tests is summarized in Table 6.1, for the Phase 2 and 2+ tests, and in Table 6.2, for the Phase 3 tests. Similarly, observed target rodlet disruptions are presented in Table 6.3. Measured temperatures and pressure instrumentation data will be presented in Section 6.4. The measured aerosol particle results and evaluations are described in Section 7.

Table 6.1 General Phase 2+ Test and Aerosol Particle Sampler Information

TEST # date	Notes: Test Modifications	Sampling Time	Aerosol samplers	Flow Rate L/min
Phase 2 / Phase 3 Cross-Over Tests				
2/9C 11/18/04	new Phase 3 test chamber, Zirc tube only, operations	10 sec	4 Marple 4 LPS	1.90, 1.95, 1.92, 1.98 L/min
Phase 2+ Tests				
2/10A 4/28/05	CeO_2 + 6 FP disks new Phase 2+ test chamber	10 sec	4 Marple * 4 LPS	0, 0, 0, 0 Lpm * (* valve relays dislodged)
2/10B 6/09/05	CeO_2 + 6 FP disks (replicate)	10 sec	4 Marple 4 LPS	1.68, 1.95 1.95, 1.71 Lpm
2/10C 7/19/05	CeO_2 + FP doped CeO_2	10 sec	4 Marple 4 LPS	1.67, 1.90 1.92, 1.71 Lpm
2/10D 7/27/05	CeO_2 + FP doped CeO_2 (replicate)	10 sec	4 Marple 4 LPS	1.91, 1.65 1.92, 1.73 Lpm
2/10E 8/11/05	German HAW/HLW glass pellets w/dopants	10 sec	4 Marple 4 LPS	1.95, 1.65 1.92, 1.73 Lpm
2/10F 8/18/05	German HAW/HLW glass w/dopants (replicate)	10 sec	4 Marple 4 LPS	1.95, 1.65 1.95, 1.72 Lpm
2/10G (6/2006)	CeO_2 + FP doped CeO_2 (in Germany)		vertical elutriator, Berner impactor	
2/10H (6/2006)	CeO_2 + FP doped CeO_2 (in Germany, replicate)		vertical elutriator, Berner impactor	

Table 6.2 Phase 3 Test and Aerosol Particle Sampler Information

TEST # date	Notes: Test Modifications	Sampling Time	Aerosol samplers	Flow Rate L/min
Phase 3 DUO_2 Tests				
3/2 (A) 10/14/05	DUO_2, no FP with air flush, 1 bar	10 sec (+1 to 11 sec)	4 Marple 4 LPS	1.91, 1.66 1.92, 1.71 L/min
3/5 (B) 1/12/2006	DUO_2, no FP, with air flush, 40 bar He rodlet	10 sec (+1 to 11 sec)	4 Marple 4 LPS	1.95, 1.90 1.92, 1.98 L/min
3/1 (C) 3/9/2006	DUO_2, with FP disks with air flush, 1 bar	10 sec (+2.5 to 12.5 sec)	4 Marple 4 LPS	2.16, 2.16 2.18, 2.14 L/min

Target Rodlet Disruptions: The observed effects of an explosive HEDD jet impact on the Phase 2/ Phase 3 test 2/9C with an empty Zircaloy cladding tube, the Phase 2+ tests 2/10A through test 2/10F, and the first three Phase 3 DUO_2 test rodlets were fairly consistent with all previous Phase 2 tests, about 21-30 mm *average* gap [in Molecke et al., 2005a]. Table 6.3 lists the measured gap (average and ranges) in the Zircaloy cladding tubes for all tests in this report. This table also lists the observed number of target pellets particulated, the length of particulated pellets, the gross weight of the disrupted pellets, the weight of "blowback" particles found at the outer ends of the post-test rodlet segments, and the weight of "impact debris" (surrogate particles, soot, metallic debris, etc.; sometimes including the CSC copper slug) collected from (vacuuming and wiping) inside the post-test chamber.

Table 6.3 Observed Post-Test Rodlet Disruptions, Phase 2+ and Phase 3 Tests

Phase 2 Test #	Zircaloy Tube Gap mm (ave.)	# of Pellets particulated	Pellet Length particulated	Pellet Weight Disrupted (particles + dopants)	"Blowback" particles	Impact Debris (in chamber)
2/9A	25-(30)-35	5.8	40.8 mm	18.6 g		24.01 g
2/9B	21-(25)-29	6.8	51 mm	21.7 g	1.09 g	45.53 g
2/9C	15-(23)-28	- -	- -	- -	- -	
2/10A	28-(32)-34	5.6	~48 mm	18.4 g	1.31 g	37.14 g
2/10B	25-(30)-35	5.0	~42 mm	16.5 g	0.49 g	25.84 g
2/10C	17-(22)-24	5.8	32.3 mm	12.5 g	0.77 g	21.69 g
2/10D	25-(28)-34	6.4	32.8 mm	14.4 g	0.99 g	33.91 g
2/10E	27-(30)-40	6.5	46 mm	7.5 g		19.72 g
2/10F	22-(27)-29	6.5	46 mm	7.5 g		23.92 g
2/10G						
2/10H						
3/2 (A)	24-(27)-30	3.1	43 mm	29.9 g		30.1 g
3/5 (B)	26-(29)-32	3.1	44 mm	29.9		112.2
3/1 (C)	27-(32)-37	3.4	47 mm	32.2		22.5

The CSC jet impacts on all of the target rodlets tested this period (in Table 6.3) produced an average measured gap of 24-(28)-32 mm in the Zircaloy cladding tube. The total Zircaloy tubing gaps observed varied from 15-40 mm, primarily due to jagged flaps of Zircaloy of different lengths. Refer to Figures 6.1 through 6.7 showing Phase 2+ post-test damaged rodlet ends and, in some cases, views of the pellets within.

Figure 6.1 Test 2/9C Post-test Rodlet

Figure 6.2 Test 2/10A and 2/10B Post-test Rodlet

Figure 6.3 Test 2/10A and 2/10B Rodlet Ends ➡

Figure 6.4 Test 2/10C Post-test Rodlet

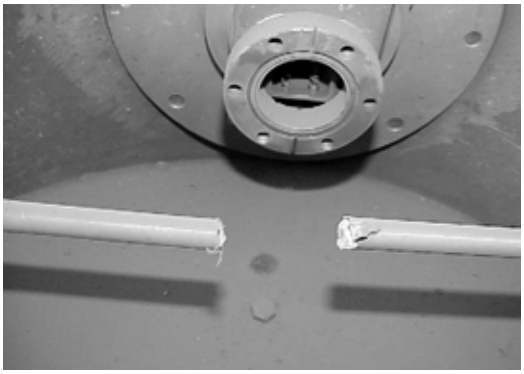


Figure 6.5 Test 2/10D Post-test Rodlet

Figure 6.6 Test 2/10E Post-test Rodlet

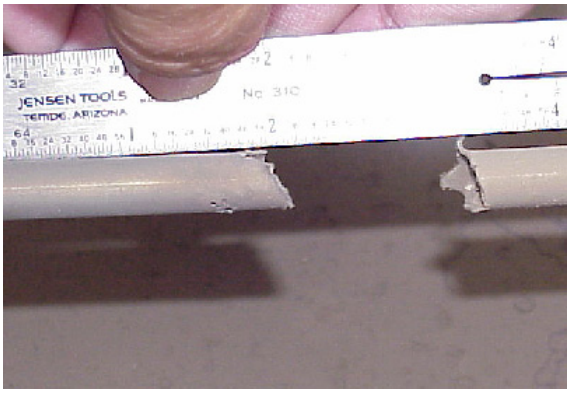


Figure 6.7 Test 2/10F Post-test Rodlet

Phase 2+ tests with cerium oxide pellets, 2/10A through 2/10D, always had well defined pellet damage. In all cases, there were always two whole pellets with flat faces remaining on one end of the rod, while there was between 1 to 2.6 pellets remaining on the other rodlet piece, usually with a very jagged or lumpy remaining inside (center) face. The end-most pellets (away from the center-point) were essentially undamaged. The two tests with HAW/HLW glass pellets, 2/10E and 2/10F, had some almost flat but damaged pellet faces, plus some very rough, almost concave (see Figure 6.6) or diagonal pellet residual faces.

The post-test rodlet ends for Phase 3 DUO_2 test 3/2 (A) could not be examined closely because of contamination control concerns. However, they were weighed and photographed; refer to Figure 6.8. This rodlet damage area is quite similar to the disrupted length of previous Phase 2 test rodlets containing cerium oxide or glass pellets, listed in Table 6.3. There was also no visible damage to the welds at the outer ends of the rodlet, a point of interest. Figures 6.9 and 6.10 show the post-test rodlet ends for tests 3/5 (B) and 3/1 (C), respectively.

Figure 6.8 DUO_2 Test 3/2 (A) Post-test Rodlet

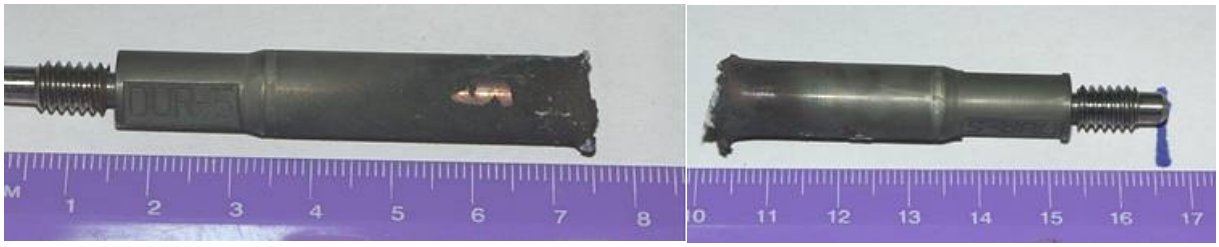


Figure 6.9 DUO_2 Test 3/5 (B) Post-test Rodlet Ends

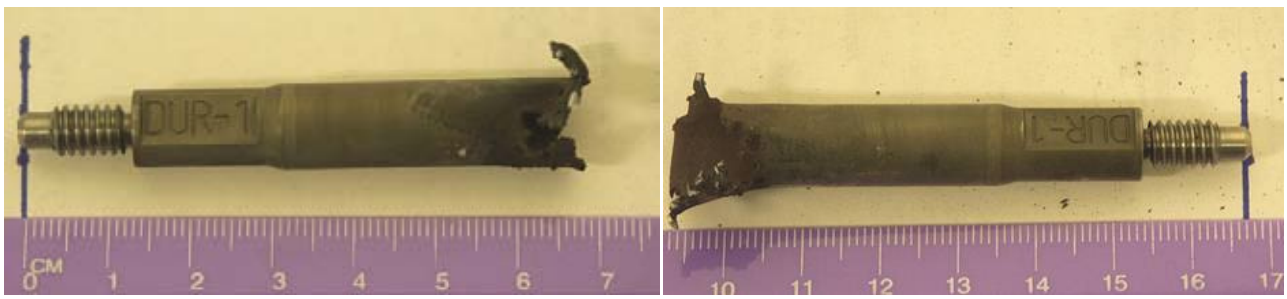


Figure 6.10 DUO_2 Test 3/1 (C) Post-test Rodlet Ends

6.1 Phase 2 / Phase 3 Cross-Over Tests, Variables and Observations

The Phase 2 / Phase 3 cross-over series of tests was added to the original test design program in 2004, and the first two tests, 2/9/A and 2/9B, were completed in FY 2004 [Molecke et al., 2005a]. These Phase 2 / Phase 3 tests were intended to bridge the equipment and facility gap between earlier Phase 2 surrogate tests with CeO_2 pellets, performed in the initial vertical aerosol collection-explosive containment chamber ("Grandma," Figure 4.6, in [Molecke et al., 2005a]), and the Phase 3 tests with DUO_2 test rodlets to be performed in the new Phase 3 test chamber ("Tweety Bird," shown in Figure 5.4). The purpose of these cross-over tests was to exercise and demonstrate the full Phase 3 test system and operational controls, to institute several new techniques, and also to collect surrogate target aerosol data, all in a non-radioactive test environment.

Phase 2 / Phase 3 cross-over tests 2/9A and 2/9B contained cerium oxide surrogate pellets in Zircaloy-4 cladding tube test rodlets (the "Phase 2" segment). Test 2/9B was very similar to test 2/9A, but was performed with an internal test chamber atmosphere of inert nitrogen gas [Molecke et al., 2005a]. Available instrumentation and gravimetric data on particle size distributions were documented in [Molecke et al., 2005a]. The post-test chemical and elemental analyses on aerosol particles for these two tests are included herein, in Appendix A, and are provided to support subsequent comparisons to aerosol analyses from other tests in this program.

Test 2/9C performed in FY 2005 was a "blank" test, using an empty Zircaloy-4 cladding tube, 152 mm (8 inches) long, and 10.6 mm outer diameter, un-pressurized. There were no target cerium oxide pellets or dopant disks. The internal test chamber had an air atmosphere. This test was performed at the SNL ECF remote Gun Site facility primarily for operational readiness, procedure check-out, and Marple impactor handling by SNL Technical Area V nuclear personnel, assisted by SNL aerosol department personnel, plus post-test chamber residual debris clean-out operations. This test also served as a demonstration for international program participants during the 8th Technical Meeting of the International Working Group for Sabotage Concerns of Transport and Storage Casks, WGSTSC, at Sandia National Laboratories; refer to Figures 6.11 and 6.12. Aerosol sample data from the four Marple impactors and the four LPS were collected and gravimetrically analyzed. We also used a HEPA vacuum collector with sampling filter socks to vacuum up residual "impact debris" in the aerosol chamber. In addition, we used filter paper wipers to collect soot and particle samples from the outside surface of each of four internal sampling tube pipes, and similar sample "brushings" from inside of the sampling pipes, using an appropriately sized rifle cleaning brush. Test 2/9C gravimetric data on particle size distributions are included in Appendix A; no chemical analyses of any of these samples were performed.

Two final Phase 2 / Phase 3 tests, 2/9D and 2/9E, similar to test 2/9C, are planned to be performed at the SNL GIF facility in 2006-07, *as if* they contained radioactive target rodlets, primarily for Technical Area V nuclear operational readiness, procedure check-out, and demonstration purposes. These two tests are intended to be the operational and proof-test bridge to the conduct of highly radioactive Phase 4 spent fuel tests in the GIF.

6.2 Phase 2+Tests 2/10A through 2/10F, Variables and Observations

Test 2/10A was the first Phase 2+ test, with the new, semi-open explosive/aerosol test chamber, shown in Figure 4.5, with four complete aerosol collection assemblies (valves, Marple impactors, large particle separator, vacuum bottle, HEPA filter, etc.). The new test apparatus allows improved, top-lid access to the interior and debris recovery and surface deposit characterization was expected to be good. This test used 9 cerium oxide pellets in Zircaloy tubes (un-pressurized), with 6 dopant disks, and was specifically intended to evaluate the effects of fission product dopant type

and distribution; this test is not radioactive. The chamber internal valve opened at -4 seconds, closed at +1 seconds after CSC detonation.

Figure 6.11 Test 2/9C WGSTSC Group 1

Figure 6.12 Test 2/9C WGSTSC Group 2

During conduct of this test, there was a problem with wiring connections to the primary and secondary control valves on all top-mounted aerosol sampling systems; they did not open, and NO aerosol source-term samples were obtained. It was subsequently determined that the explosive pressure pulse from the CSC, or possibly a fragment, dislodged the relays in the valve switch system. This prevented any flow into the sampling systems. Following this test, the wire locations were repositioned and this problem was resolved. Only the temperature and internal particle debris data are reported herein. Not all of the internal thermocouples survived after detonation of the CSC; if data from specific thermocouples are not plotted in the graphs in Section 6.2.2, the data were not usable.

Post-test, the top (lid) of the test chamber was removed and particulate debris inside was sampled with a HEPA vacuum with a filter sock apparatus attached to the end of the hose. The filter socks were obtained from Midwest Filtration apparatus. The HEPA vacuum process is illustrated in Figure 6.13. These particulate samples were packaged and sent to an analytical chemistry laboratory for elemental analyses.

SNL Analytical Chemistry, Dept. 1822, previously had provided all chemical analyses for the surrogate Phase 2 aerosol samples through test 2/9B, and provided some peripheral support for the Phase 2+ surrogate tests. SNL Dept. 1822 major contributions to this overall program have been the development of the digestion scheme for analysis of the debris and aerosol samples collected from these tests, the analysis of samples from field tests and laboratory preparations, and the presentation of the data in a format in which the important details from the analysis may be readily found. Because SNL Dept. 1822 cannot accept radioactive materials for analysis, we have contracted the General Engineering Laboratory, GEL, in Charleston, South Carolina, to perform future DUO_2 particulate mechanical sieving, dissolution, and following chemical elemental analyses using Inductively Coupled Plasma-Mass Spectroscopy, ICP/MS. GEL was also tasked with performing analyses of the surrogate material aerosol particles, starting with Phase 2+ test 2/10A.

Figure 6.13 HEPA Vacuum Sampling of Post-test Aerosol Chamber Particulate Debris

Test 2/10B, the second Phase 2+ test, was a replicate of test 2/10A. Operation of the chamber internal valve was modified slightly; it was opened at -4 seconds (the same), but closed at +0.1-0.5 seconds after CSC detonation (new). All test aerosol sampling systems appeared to have operated properly. The only problem encountered was that two of the thermocouples installed at the bottom, front of the test chamber (visible in Figure 4.6) were destroyed by fragments within. They were only 10 mil (0.25 mm) thick. In a video taken of this test, a concrete/grout secondary fragment (from the test facility concrete pad or abutment) was seen bouncing off of a small, post-test vacuum-relief canister on one of the aerosol sampling systems in front, at ~ + 2-3 seconds. There was no observable damage to this component.

Test 2/10C and 2/10D, its replicate, were similar to the preceding tests 2/10A and 2/10B, but incorporated the new fission-product doped cerium oxide pellets, not the earlier resin-based dopant disks. These Phase 2+ test, used a total of 10 cerium oxide pellets (3 un-doped, 4 doped, 3 un-doped) in a Zircaloy tube (un-pressurized).

Test 2/10E and 2/10F, its replicate, are similar to the two preceding tests 2/10C and 2/10D, but consisted of German surrogate high-level waste (HLW/HAW) GLASS pellets that were internally doped (with fission product simulants melted into the glass) in an un-pressurized Zircaloy tube. These two Phase 2+ glass pellet tests, 2/10E and 2/10F, are somewhat similar to previous tests 2/7A and 2/7B, conducted in February 2004 [Molecke et al., 2005a], in cooperation with Fraunhofer personnel, at the SNL Gun Site. These were performed cooperatively for our German WGSTSC test partners at the Fraunhofer Institute and the GRS. Post-test aerosol samples were shipped to the Fraunhofer Institute for post-test chemical analyses.

Test 2/10G and 2/10H, its replicate, are planned to be performed in Germany in June 2006, by personnel at the Fraunhofer Institut (both the Institut für Toxikologie und Experimentelle Medizin, ITEM, and the Ernst-Mach-Institut, EMI, in Holzen, Germany). These two tests are essentially identical to tests 2/10C and 2/10D above, except that the aerosol particle collection system will use the Fraunhofer vertical elutriator particle sampling system (refer to Figure 1, Appendix A, in [Molecke et al., 2005b]) and Berner particle impactors. A primary purpose of these two tests is to cross-calibrate the aerosol results to be obtained with the Fraunhofer vertical elutriator system with

the Sandia Phase 2+ test chamber plus aerosol system. The surrogate cerium oxide pellets to be used in these tests, both un-doped and doped, were fabricated at SNL and shipped to Fraunhofer Institut ITEM for this cooperative testing.

6.3 Phase 3 Tests, Variables and Observations

Test 3/2 (A) was the first of six DUO_2 explosive aerosol-explosive tests to be performed at the SNL Explosive Components Facility. This test used the vertical explosive-aerosol test chamber, "Tweety Bird," as shown if Figure 5.4 and described in section 5.2, with four complete aerosol collection assemblies. The target rodlet used for this first test was labeled "DUR-2" (French IRSN designation); refer to Section 5.1. The internal pressure within the test rodlet was 1 bar, essentially atmospheric pressure. There were no fission product dopants in this test rodlet. The test chamber contained air, at atmospheric pressure. The total aerosol particle sampling time was 10 seconds, as in previous tests. The primary and secondary sampling valves were opened at +1 seconds after CSC detonation; then, both valves were closed at + 11 seconds. Temperatures and pressures within the top-mounted aerosol system lines were monitored for longer periods of time. The Marple impactor and LPS apparatus were loaded with fiberglass media substrates, as used in the Phase 2+ tests.

This Phase 3 test was slightly radioactive due to the depleted uranium oxide in the test rodlet, so it had to be performed with the appropriate precautions and procedures, as found in the ECF Operational Procedure [ETG-OP-DETEVAL-109-A, 2005]. Prior to the test, two "dry-run" instrumentation and procedural check-outs were performed in the preceding weeks. Radiological Work Permit (RWP) requests were checked, the staff was briefed, and then the RWPs were signed off. The entire test chamber and aerosol system was located within a large portable plastic "tent" chamber," used as a secondary barrier to radioactive particulate release, and shown in Figures 6.14, 6.15, and 6.16. The plastic tent chamber is itself located within a plastic sheeting-lined Large Walk-in (blast enclosure) Chamber in the SNL ECF building 905, room 1213A, as shown in Figure 6.17.

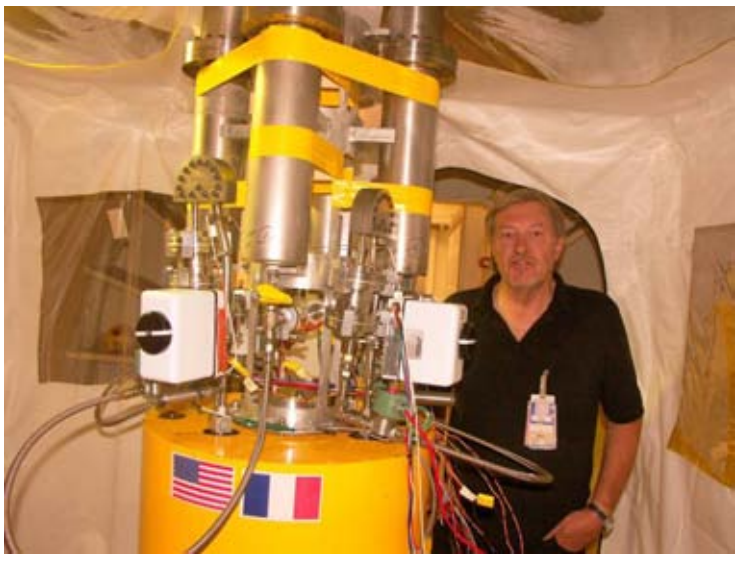


Figure 6.14 Phase 3 Test Chamber in Tent Enclosure

Figure 6.15 Phase 3 Test System in ECF Blast Chamber ➡

Figure 6.16 Phase 3 Secondary Enclosure Tent

Figure 6.17 SNL ECF Large Walk-in Chamber, 1213A

Figure 6.18 Post-test Removal of Aerosol Systems, 1

Figure 6.19 Post-test Removal of Aerosol Systems, 2

Figure 6.20 External Glove Box for Aerosol Sampling

Figure 6.21 Glove Box for Aerosol Sample Weighing

Post-test, the four aerosol apparatus sampling systems were removed from the top of the test chamber by technicians in personal protective suits, wearing respirators (refer to Figures 6.18 and 6.19) in case any particulate contamination was released. The aerosol sampling systems were surveyed for surface radioactive contamination by radiation control technicians before they were removed from the Large Walk-in Chamber (a radiation control area), and then taken to, disassembled, and individual samples weighed within a small, portable glove box located immediately outside of the Large Walk-in Chamber; refer to Figures 6.20 and 6.21.

NOTE: The particulate radioactive contamination potentially released during the aerosol assemblies removal operation was monitored and recorded as "*at or below detectable levels*." As such, RWP procedures were subsequently revised for the following Phase 3 tests, so that the use of respirators is no longer required for this aerosol apparatus removal operation.

Aerosol samples contained on aerosol impactor substrate media from disassembled Marple impactors and Large Particle Separators and those collected on cellulosic or polyester wipers from inside the test chamber were individually weighed (to 0.001 mg) on a microbalance contained within the portable glovebox (Figure 6.21). Once each filter sample is weighed, a clean, unused filter was placed onto the filter sample, sandwiching the collected aerosol debris. The samples were then individually packaged in antistatic zip-lock bags, labeled, then surveyed for external package contamination. Once this sample package is determined to be free of contamination, multiple similar samples are grouped and placed into larger packages and shipped to the GEL laboratory for post-test chemical analyses.

NOTE: During the post-test aerosol sampler disassembly process for test 3/2 (A), it was observed that the collection substrate strip for the Large Particle Separator on aerosol system # 3 had shifted either during the sampling or before, during assembly, and had noticeably obstructed the flow to the LPS and Marple impactor, impeding the collection of aerosol particles. The results for LPS #3 and Marple impactor #3 are reported herein (in Appendix A.3), but will not be used for subsequent analysis of respirable fraction or other interpretations. This problem illustrates the usefulness of having four replicate aerosol collection systems for each test.

Following the removal of all four aerosol sampling systems, on a time-available basis, the flange plate sealing the top chamber aerosol section was unbolted and removed. Subsequently, the remains of the post-test rodlet were removed, weighed, and photographed. A HEPA vacuum system was used to collect residual impact particle debris in the aerosol chamber. The aerosol chamber was then sampled with cellulosic or polyester sheet wipers to obtain particulate materials remaining on the inner surfaces of the aerosol chamber and sampling tubes within. Personnel performing these operations *are required* to wear personal protective equipment and respirators.
NOTE: During the flange plate removal process, a minimal (detectable) amount of particulate materials were released and collected on the secondary barrier tent floor below with appropriate control materials**.**

Following completion of all sampling of aerosol particle materials, SNL Radiation Protection personnel surveyed and decontaminated the Marple and Large Particle Separator units plus associated sampling system hardware assemblies to defined acceptable radiological levels (< 1000 dpm; actual measured levels were 150-300 dpm, beta-gamma radiation). This decontamination process consisted of using a combination of steam cleaning and manual swabbing/wipe-downs of cloth materials soaked in Coca Cola, then household ammonia. Finally, the secondary containment tent itself was wiped down with household ammonia.

Once everything is decontaminated, extensive surveys are taken by radiological control technicians. If the survey results are below the required levels as stated in the RWPs, then the tent, explosive test chamber, and aerosol collection units are no longer considered contaminated. The containment tent can then be reclassified (and posted with signs) from "Contamination Area" to "Radioactive Materials / Controlled Area." Contaminated equipment and wastes were bagged and stored for appropriate future disposal action. At this point, set up for the next test performance usually begins.

The second Phase 3 test, **test 3/5 (B)** was performed essentially the same as test 3/2 (A), except for one variable: the internal pressure within the test rodlet plenum region contained 40 bar (essentially 40 atmospheres, ~ 580 psi) of helium, rather than the earlier fill of air at atmospheric pressure. Similarly, there were no fission product dopants in this test rodlet. The target rodlet used for this test was labeled "DUR-5" (French IRSN designation); refer to Section 5.1. The test chamber contained air, at about atmospheric pressure for this test, the same as the first test. The Marple impactor and LPS apparatus were loaded with quartz fiber substrates, as opposed to fiberglass media used in the preceding tests. This change was mandated by chemical analyses received after 3/2 (A) was performed that indicated significant amounts of impurities contained within the fiberglass filter media; refer to Section 7.4.

Following conduct of test 3/5 (B), a new technique for the cleaning and decontamination of the inside of the test aerosol chamber was developed by the radiological control team. This technique involved "sand blasting" of the inside of the test chamber with glass beads, followed by HEPA vacuuming of residual glass, then using steam cleaning. (The glass beads were chemically analyzed to determine if they contained a significant amount of cesium or strontium, or other impurity concentration; they did not.) No Coca Cola and ammonia liquid wipe-downs were needed. The RWP procedure requires that the residual contamination level must be < 1000 dpm (beta gamma activity); a post-cleaning level of 150-300 dpm was measured and determined to be very adequate.

The third Phase 3 test, **test 3/1 (C)** was performed essentially the same as test 3/2 (A), except for one variable: two internal fission product dopant (non-radioactive) disks, were included within the rodlet assembly, one on either side of the central DUO_2 pellet; refer to Section 5.1 and Figures 5.2 and 5.3. Similarly, the internal pressure within this test rodlet plenum region was 1 bar (essentially atmospheric pressure) and the test chamber contained air, at about atmospheric pressure. The target rodlet used for this test was labeled "DUR-1" (French IRSN designation); refer to Section 5.1.

Aerosol sampling for test 3/1 (C) was performed for a total of 10 seconds after CSC detonation, the same as before. However, rather than sampling from +2.5 seconds to +12.5 seconds after detonation, the aerosol scientists requested a revised timing regime that was implemented. At time = +0 seconds post-detonation, the primary ball valves are to start being opened. At time = +2.5 seconds, the primary ball valves are fully open, and then open the secondary Asco sample valves are opened. At time = 12.5 seconds, the secondary Asco valves are closed, but the primary ball valves are left open. At time = +10 min, the primary ball valves are closed. Electronic timing marks are recorded with all of the other data for the charge denotation, plus the primary and secondary valve opening and closing timing as well.

The four Marple impactor and LPS apparatus for test 3/1 (C) were loaded with either quartz fiber substrates or Mylar substrates sprayed with silicone oil, to hold particulates; two aerosol systems had quartz fiber, two had Mylar. This modification was made because it was observed that the quartz fibers were both twice as thick as the earlier fiberglass substrate and somewhat brittle.

Small pieces of the edge of the quartz fiber substrate could stick to the surrounding apparatus and flake off, compromising (only) the measured gravimetric weights. In addition, multiple separate impact particle debris samples were collected by a HEPA vacuum system and a pre-separator paper liner (collection bag). Chemical analyses for these particulate samples, including depleted uranium and fission product dopants are not yet available for this report.

NOTE: As in the first Phase 3 test, the quartz fiber collection substrate for one of the Large Particle Separators on aerosol system # 2 shifted either during assembly or during sampling for test 3/1 (C), and partially obstructed the flow to the impactor, possibly impeding the collection of aerosol. The results for that impactor #2 will be reported, but will not be used for analysis. Mylar substrates will be used for all future tests, which should solve this problem.

6.4 Instrumentation Results, Temperatures and Pressures

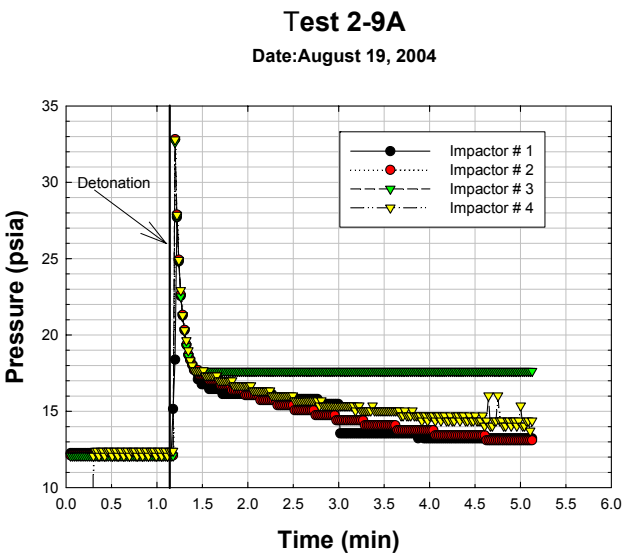
The measured pressures and/or temperatures measured within all four aerosol sampling systems on Phase 2 / Phase 3 cross-over tests 2/9A, 2/9B, and 2/9C are shown in Figures 6.22, 6.23, and 6.24, respectively. The measured peak temperatures within the aerosol sampling systems tubing, *above the aerosol test chambers*, never increased more than ~ 18 ºC above ambient, to a maximum of about 40 ºC. In addition, the observed post-CSC peak detonation pressures within the four aerosol sampling systems rapidly increased about 21 psi (1.4 bar), then decreased.

NOTE: The sampling system for impactor assembly #3 in test 2/9A inadvertently did not contain a flow controlling orifice. As a result, it can be observed in Figure 6.22 that the post-detonation pressure drop for sampling system #3 is higher than the other three sampling systems, and the observed temperature rise for Thermocouple #3 is greater. Consequently, no particle data analyses are reported for test 2/9A, sampling system #3.

The measured temperatures and pressures for the Phase 2+ series of tests were obtained both within the sampling system tubes above the aerosol test chamber and *within* the aerosol chamber itself (refer to Figure 4.9 and Table 4.3), as was the case for previous Phase 2 tests 2/6A, 2/6B, and 2/8A – 2/8D [Molecke, et al., 2005a]. The measured temperatures for test 2/10A are shown in Figure 6.25. The measured temperatures and pressures for test 2/10B are shown in Figures 6.26 and 6.27, respectively. Similarly, the measured temperatures for test 2/10C and test 2/10D are shown in Figures 6.28 and 6.29, respectively and the measured pressures for test 2/10C and test 2/10D are shown in Figures 6.30 and 6.31, respectively. The measured temperatures and pressures for test 2/10E are shown in Figures 6.32 and 6.33, and the temperatures and pressures for test 2/10F are shown in Figures 6.34 and 6.35, respectively.

The maximum, peak temperatures measured within the aerosol chambers used in Phase 2 tests 2/6A and B, 2/8A-2/8D, and 2/10A-2/10F varied appreciably and reached some very elevated values, as are summarized in Table 6.4. Temperatures as high as 840 ºC, for test 2/6A and B, and 1300 ºC, for test 2/10A, were recorded.

Temperatures measured by thermocouples installed within the aerosol chambers were quite dependent on their locations (refer to Figure 4.9), thermocouple response time, shielding from hot explosive gases, etc. However, such peak temperatures may provide some correlation with measured internal pressures, some help in an interpretation of measured Respirable Fractions (refer to Section 7), and a potential correlation to measured enrichment factors for volatilized fission products (refer to Section 7.3 and 7.4).



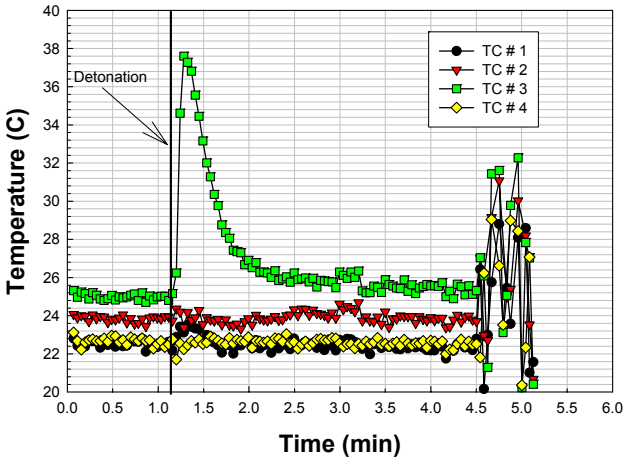


Figure 6.22 Test 2/9A Aerosol Sampler Pressures and Temperatures

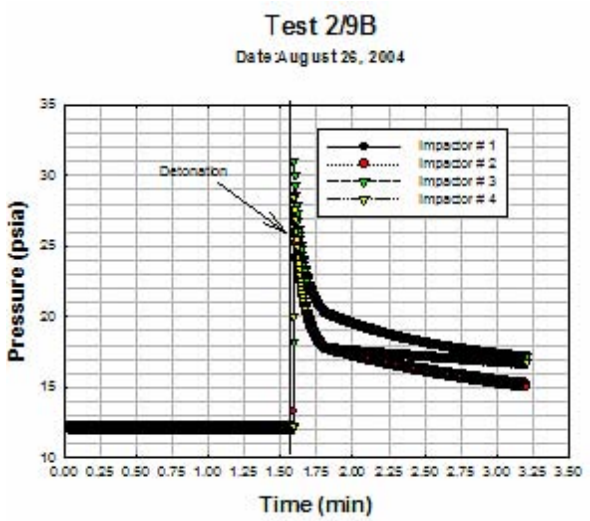


Figure 6.23 Test 2/9b Aerosol Sampler Pressures

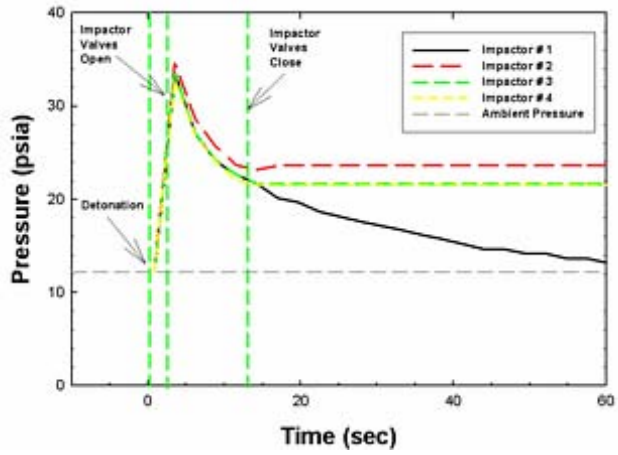


Figure 6.24 Test 2/9C Aerosol Sampler Pressures

Table 6.4 Peak Measured Temperatures Inside of Phase 2 and 2+ Aerosol Chambers

Phase 2 Test Peak Temperature		**Phase 2+ Test** Peak Temperature	
2/6A	840 ºC	**2/10A**	1300 ºC
2/6B	840 ºC	**2/10B**	230 ºC
2/8A	220 ºC	**2/10C**	280 ºC
2/8B	200 ºC	**2/10D**	330 ºC
2/8C	180 ºC	**2/10E**	260 ºC
2/8D	340 ºC	**2/10F**	330 ºC

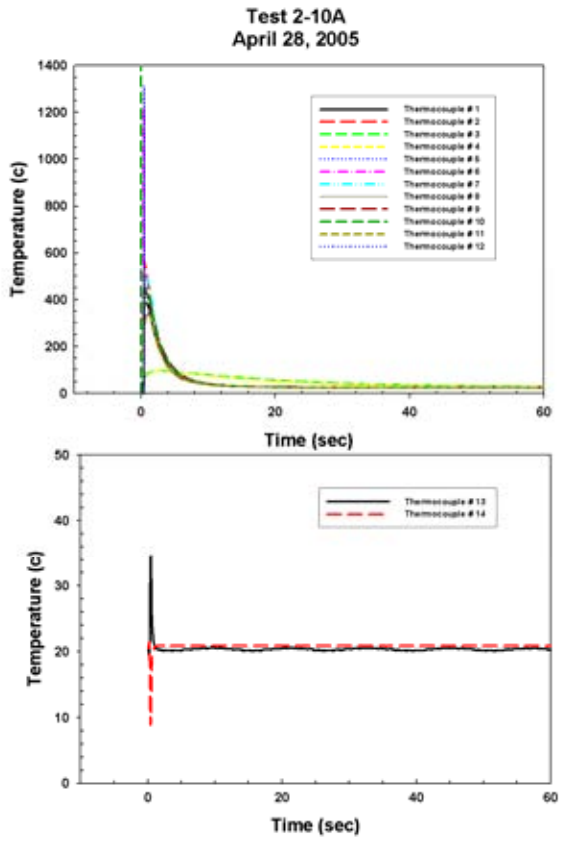


Figure 6.25 Test 2/10A Temperatures

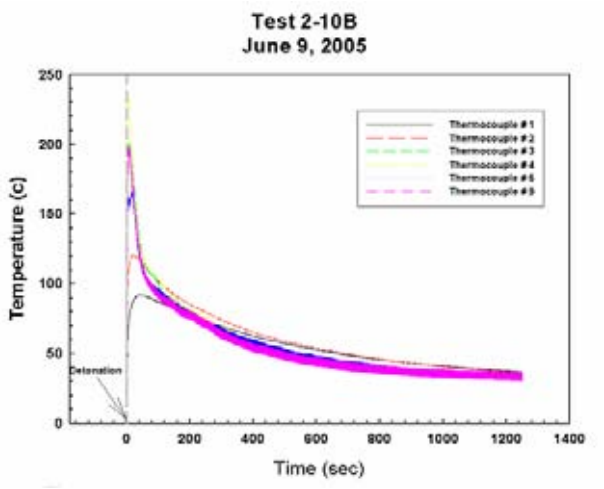


Figure 6.26 Test 2/10B Temperatures

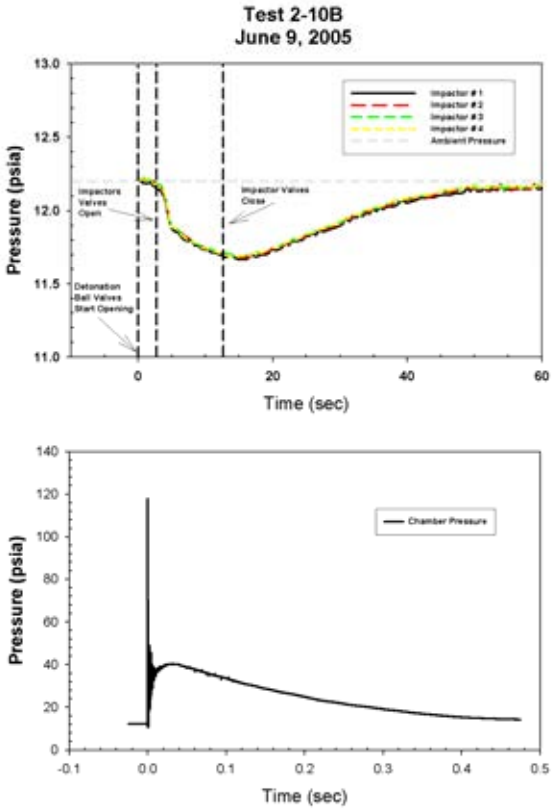


Figure 6.27 Test 2/10B Measured Pressures

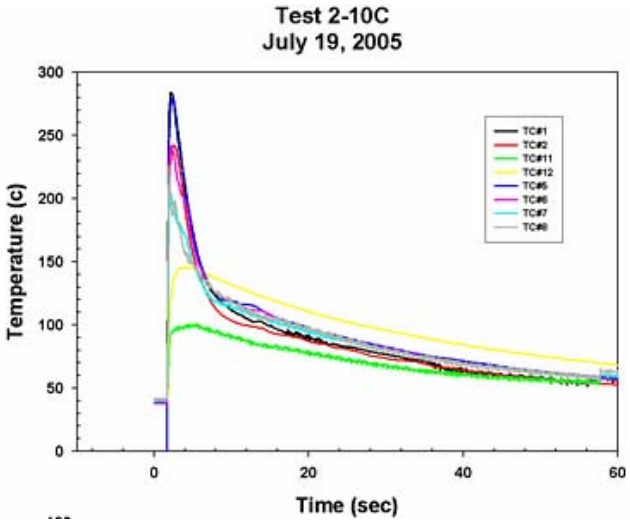


Figure 6.28 Test 2/10C Temperatures

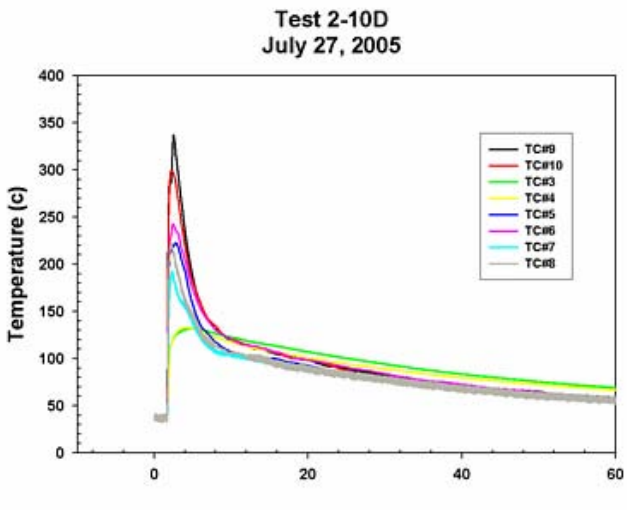


Figure 6.29 Test 2/10D Temperatures

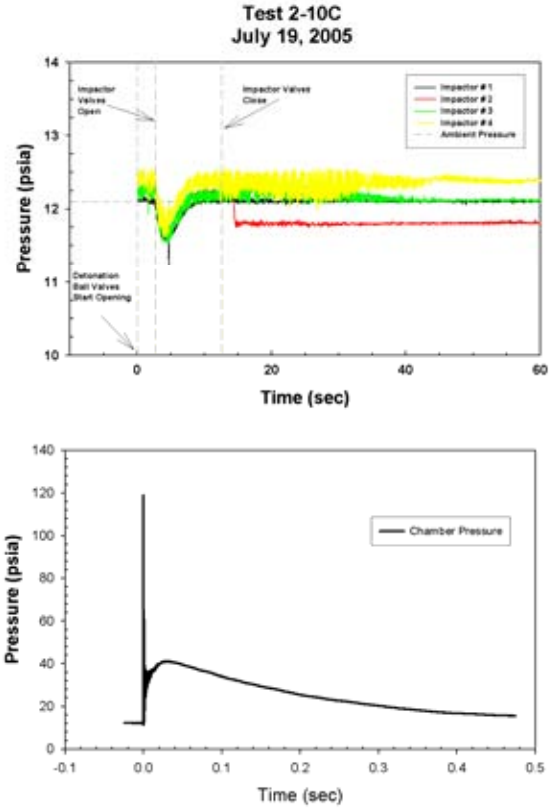


Figure 6.30 Test 2/10C Measured Pressures

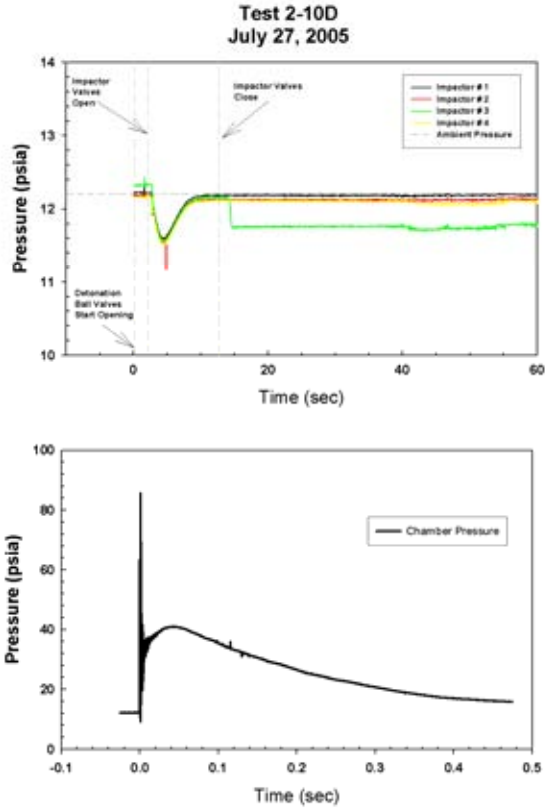


Figure 6.31 Test 2/10D Measured Pressures

The measured temperatures and pressures for the Phase 3 series of tests were obtained *only* in the aerosol sampling lines *above* the test chamber, just downstream of the Large Particle Separators. The measured temperatures and pressures for test 3/2 (A) are shown in Figures 6.36 and 6.37, for test 3/5 (B) are shown in Figures 6.38 and 6.39, and for test 3/1 (C) are shown in Figures 6.40 and 6.41, respectively.

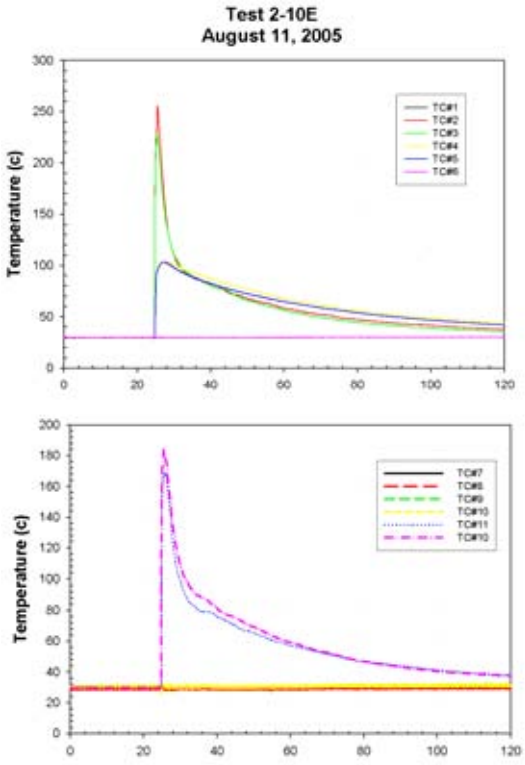


Figure 6.32 Test 2/10E Temperatures

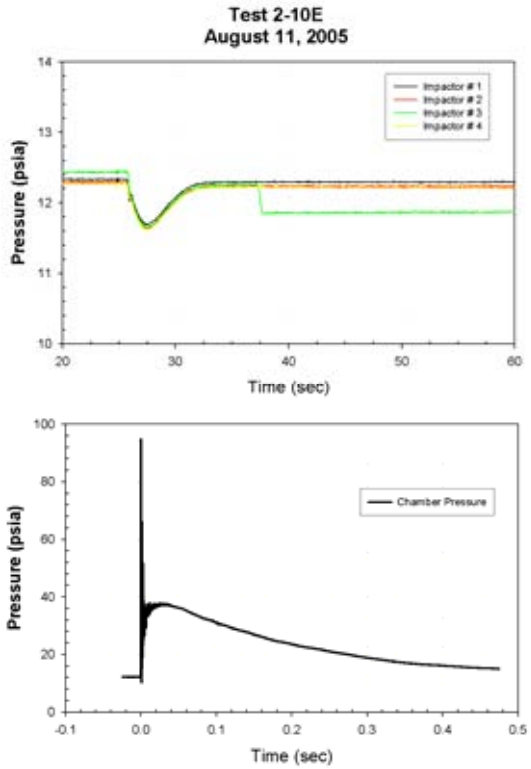


Figure 6.33 Test 2/10E Measured Pressures

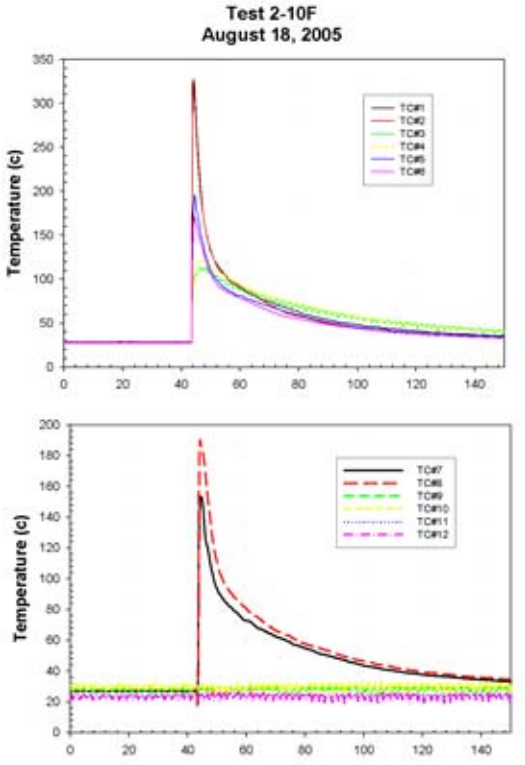


Figure 6.34 Test 2/10F Temperatures

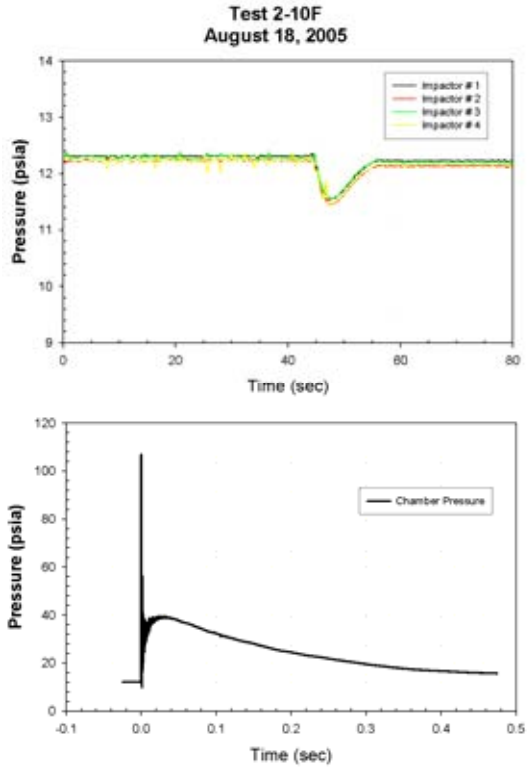


Figure 6.35 Test 2/10F Measured Pressures

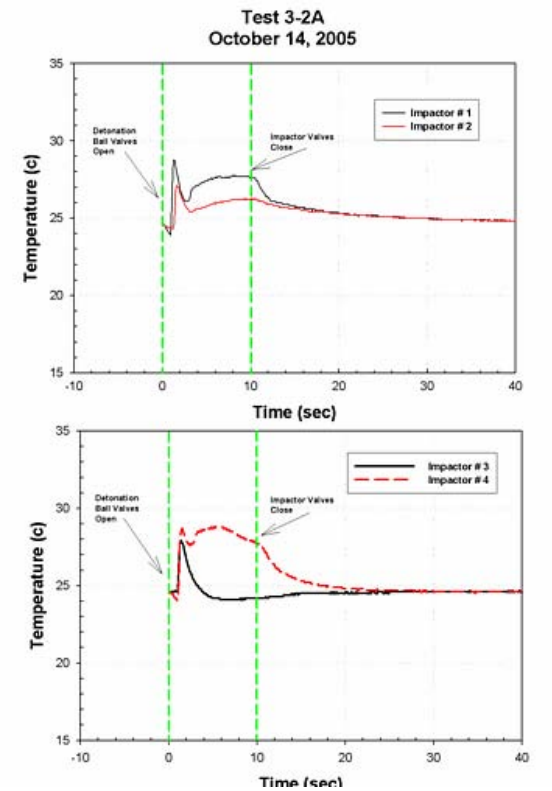


Figure 6.36 Test 3/2 (A) Aerosol Sampler Temperatures

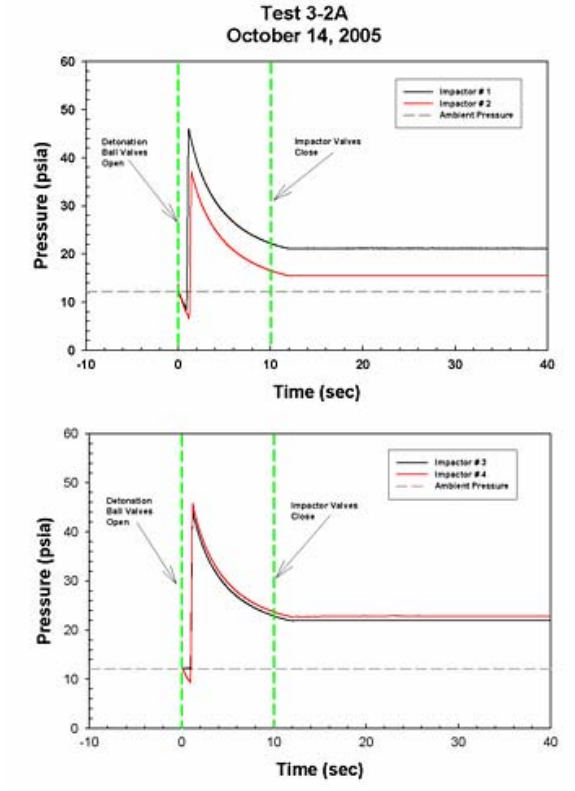


Figure 6.37 Test 3/2 (A) Aerosol Sampler Pressures

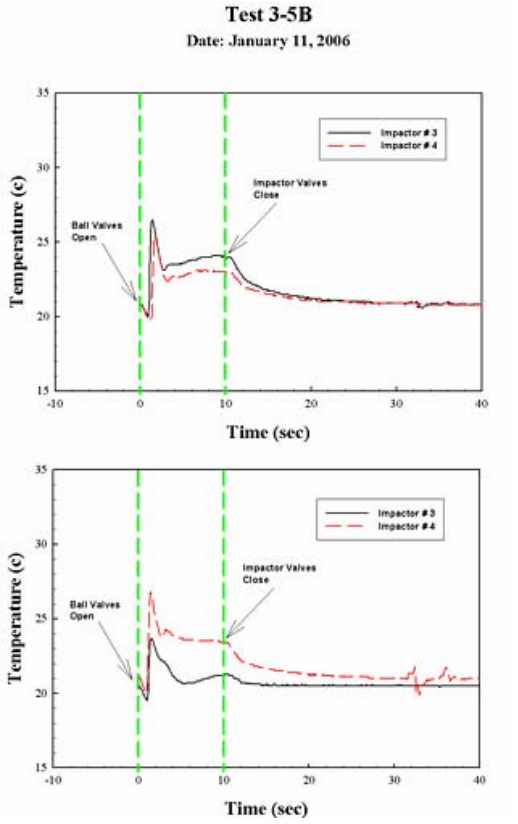


Figure 6.38 Test 3/5 (B) Aerosol Sampler Temperatures

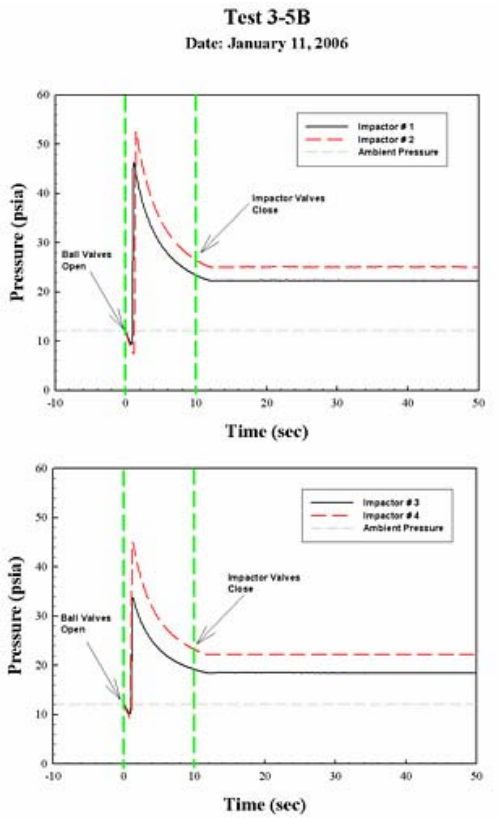


Figure 6.39 Test 3/5 (B) Aerosol Sampler Pressures

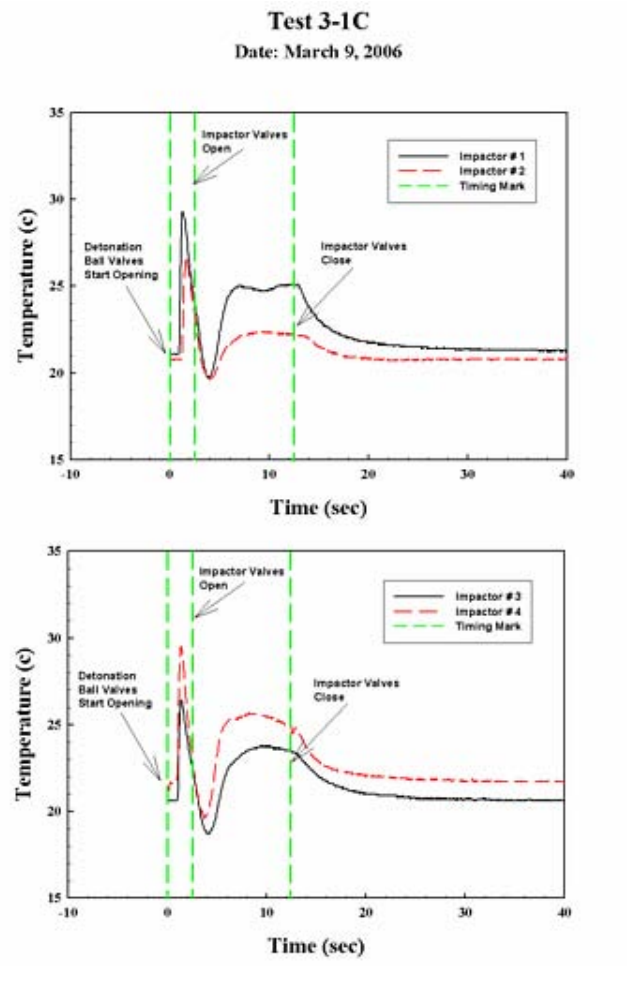


Figure 6.40 Test 3/1 (C) Aerosol Sampler Temperatures

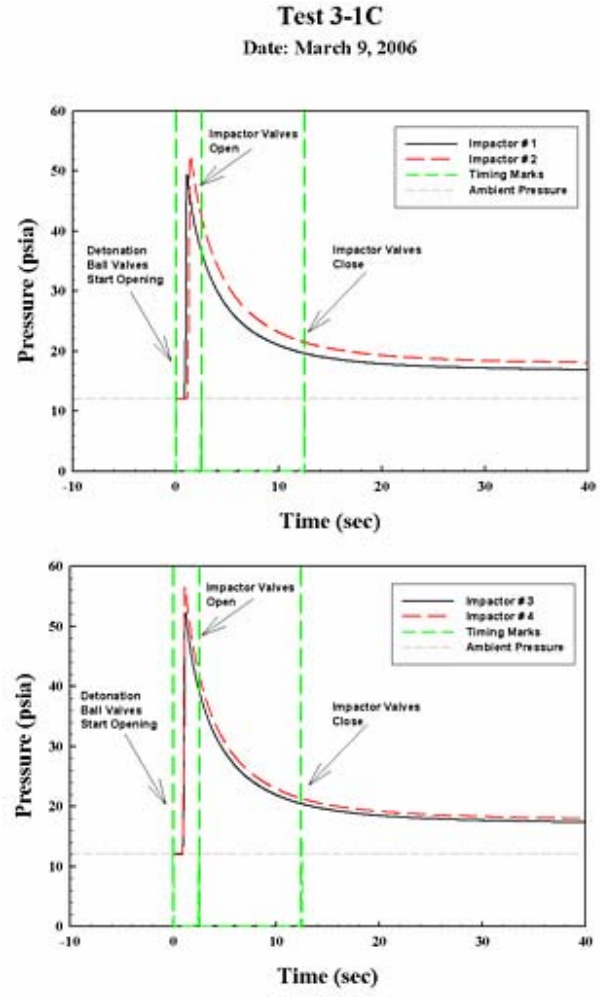


Figure 6.41 Test 3/1 (C) Aerosol Sampler Pressures

6.5 Status of Ongoing Testing, Sampling, and Analyses

Significant amounts of testing and analyses have been performed during FY 2005 and the first half of FY 2006. However, not all analyses have been completed. Aerosol data collected on the Large Particle Separators, with data relevant to 30 to 100 μm AED particles still remains to be interpreted. The LPS calibration work is planned along with Marple impactor laboratory calibration and inlet characterization. Final laboratory calibrations of the aerosol sampling system components, and diagnostics thereof, remain to be completed.

Particle samples were collected within internal test chamber sample tubes and from test chamber inner surfaces. These samples have been weighed and chemically analyzed. However, interpretations of these sampling line and surface losses are still in process. Sample line particle deposits have been collected beginning with the 2/10 test series and were weighed and analyzed for the later tests in the series. It is interesting to note that the mass of material collected in the sample lines up to the LPS is comparable to that collected in the LPS and impactor. Preliminary examination indicates that most of the deposition occurs in the sample lines after the manually operated isolation ball valve at the top of the chamber, that is, in the short line from the chamber top to the large control ball valve, the ball valve itself, and the line from the valve to the LPS. Initial explanation is that we may be seeing thermophoretic or diffusiophoretic deposition in these lines; in this case, deposition is largely independent of particle size and the collected mass would be added proportionally to the measured mass in the samplers. Particle deposition in the sampling lines may cause uncertainties in the measured RF values, possibly by two times those reported herein. Alternatively, turbulent deposition could be responsible for the deposition in which case, larger particles would be preferentially deposited in the sample tubing. Chemical analysis should shed light on this issue so that we can determine the size makeup of these deposits and correctly attribute the masses to the measured size distribution.

Sampling takes place during a pressure and temperature transient and analysis to determine the chamber volume sampled during this time period and the effect of the sample line volume itself is being conducted. Currently, a reasonable estimate is being made using the sample flow rate and sample time. Transient temperatures and pressures in the aerosol chamber may introduce uncertainty on the order of +/- 20%. Final laboratory calibrations of the aerosol sampling system components, diagnostics thereof, and particle deposition effects remain to be completed.

7. Phase 2, 2+ and Phase 3 Test Aerosol Particle Data

The data and analyses presented in this section are updated from those presented at the 9th and 10th Technical Meetings of the WGSTSC [Molecke, et al., 2005c, Brockmann et al., 2005], in May and November 2005. The aerosol data for surrogate cerium oxide and dopant fission product materials are considered prototypical of similar data to be obtained from actual spent fuel materials in later Phase 4 tests in this program. Aerosol data from the first two Phase 3 depleted uranium oxide target rodlets are included herein; aerosol results from the third, test 3/1 (C) will be documented later.

Following the CSC jet impact with the test target rodlets, aerosol particulates are generated rapidly. As measured, more than 10 g/m^3 of respirable particles are generated in the test chamber; a large fraction of this material, about ½, is carbon soot from the explosive CSC. The high soot concentration limits the total sampling time to 10 seconds, in order to prevent Marple impactor overloading.

The sampling efficiency of the Marple impactor and Large Particle Separator apparatus is very high and is a function of particle size, rapidly changing temperatures and pressure within the sampling system. For respirable size particles, the efficiency is close to 100%, or, if thermophoretic deposition losses are *assumed* to be 50%, then the overall efficiency for respirables is about 50%. The overall sampling efficiency for aerosol particles of 50 µm AED size is estimated to decrease to about 40%. Larger, non-aerosol particles are settling out during the 10 second sampling period. Respirable and aerosol particle losses in the sampling lines are still being determined in supporting laboratory characterization tests. These losses include thermophoretic particle deposition, which occurs on cooler initial portions of sampling tube interior surfaces. Observed deposition included: Minimal particulate deposition was observed in the sampling tube from the top of the aerosol chamber interior to the manual isolation ball valve. Significant deposition was observed in sample tubing between the manual isolation ball valve and Large Particle Separator (LPS). Data collected for deposits on the inside of sampling tubes is still being analyzed. Also, diffusiophoretic particle deposition losses may occur on test surfaces on which water vapor condenses. The water is generated as a byproduct in the explosive detonation, and may reach super-saturation as the sampled gas cools in the sampling lines. Therefore, the following aerosol sampling data reported in this report are still considered as *preliminary data*. They were analyzed without correction for inlet sampling efficiency, chamber losses from settling and thermophoretic deposition, or gas sample volume taken at a temperature considerably higher than the volume measured at the flow orifice. Such sampling characterization results and corrections will be quantified and reported in the future.

7.1 Aerosol Results for Cerium Oxide

The ***respirable fraction*** **(RF)** produced when the CSC jet impacts a target rodlet is the fraction of a specific material (cerium oxide, uranium oxide, zirconium, fission product, etc.) *produced* (in the rod swept volume, for particles of size 10 µm AED and smaller) divided by the total amount of those material particulated. Respirable fractions for CeO_2, Zr, and Cs have been calculated from the aerosol measurements taken in all the Phase 2 and Phase 2+ tests to date (2/1A through 2/10D) based upon the measured aerosol size and concentration and the amounts of those materials dispersed into the test chamber.

The particle masses were directly measured after each test. The sample volume is taken as the flow through the orifice at the orifice temperature, which is taken as ambient temperature prior to the test. All relevant new aerosol particle data are compiled in Appendix A of this report and earlier data in Appendix A of [Molecke et al., 2005a], for tests performed in FY 2004. We presume

that the later tests using multiple Marple impactors yielded our best quality, and largest amount of interpretable data. Based on the data collected for all Phase 2 and 2+ tests, for completeness, the calculated respirable fraction results are summarized in Table 7.1 and Figure 7.1. NOTE: Respirable Fraction test results for the 2/10 series of tests are slightly revised from values reported in November 2005 [Molecke, et al., 2005c] to account for flow-dependent Marple impactor performance.

The calculated average CeO_2 respirable fraction for all Phase 2 and 2+ tests based on the Marple impactor data in Table 7.1 is 0.61 +/- 0.25% (with a 99% confidence interval). This is appreciably lower than similar values calculate from all gathered data, 1.34 +/- 0.56 %, which included the earlier Berner and Respicon data. NOTE: Results from these older tests (2/2A through 2/3B, in particular) may have higher RF values due to use of different, partially vented square-box aerosol chambers [Molecke et al., 2004a].

Also observe that the CeO_2 RF *range* of 0.4% to 0.9% for the Phase 2 and 2+ tests Marple data overlaps the RF range 0.8% to 1.9% for all (old and new) data. Another possibility is that the earlier samples may have collected more material (e.g., a lower thermophoretic loss) or been sufficiently different in sampling configuration. The later data from the Phase 2+ tests and the two Phase 3 depleted uranium oxide tests with an average RF for DU of 1.31 +/- 0.41 % (with a 99% confidence interval) are more consistent with the earlier samples (excluding 2/6 and 2/9) and the 2/10 results. The respirable fraction data for DUO_2 are also presented in Table 7.7 and described in Section 7.6.1.

The cumulative mass fraction distributions for CeO_2 (presented in [Molecke et al., 2005a]) suggest mechanical fragmentation of the surrogate cerium oxide pellets without phase changes or thermal volatilization; the cerium oxide surrogate material behaves as a representative brittle material. The aerosol particle samples collected (up to 100 μm AED in size) match well with larger particulate impact debris collected within the test chamber, then mechanically sieved and analyzed. The cumulative mass fraction plots for CeO_2 are based on chemical analysis of the debris for the fraction collected below 125 micrometer sieve size and the total amount of cerium oxide dispersed in the test. The distribution has resolution below this sieve size and no resolution above the size. NOTE: The CeO_2 cumulative mass fraction distribution results do not extend up to 100% because large, non-aerosol particles were not analyzed even though the total CeO_2 disrupted mass was used for the calculation.

From observations of the Marple impactor cerium distributions in the ~ 0 through 10 μm AED respirable size range, and even up to ~ 35 μm, (as illustrated in multiple figures in Appendix A) cerium is one of the most prevalent respirable materials produced by the CSC jet explosive impact process. The other major respirable components produced are copper (from the CSC) and carbon soot (not chemically quantified nor shown in the figures). Cerium particles appear to peak somewhat over the respirable range size of 0 to 10 μm AED (maximized at about 3.5 μm, or 3.5-9.8 μm). No distinct cerium particle pattern is observed in the aerosol range from about 30 to 100 μm AED, collected with the LPS apparatus.

An important effect to consider is that the CeO_2 RF represents the small tail of a distribution produced by fragmentation. Sieve analysis of the CeO_2 in the debris indicates a mass mean debris size on the order of several hundred micrometers over the various tests, with observed variation. Even with highly repeatable fragmentation distributions characterized by small variance in the mean and spread of the distribution, the integral mass in the small tail is subject to larger variation.

Table 7.1 Phase 2 and 2+ Test Results for CeO_2 Respirable Fraction

	CeO_2 Dispersed		Cerium Oxide Respirable Fraction (%)							
Test	CeO_2 (mg)	Ce (mg)	Respicon 1	Respicon 2	Berner	Marple 1	Marple 2	Marple 3	Marple 4	Test Avg
2/1A	11304	9203	0.48%	0.28%						0.38%
2/1B	11304	9203	0.53%	0.40%						0.46%
2/2A	10209	8311	4.93%	4.00%						4.46%
2/2B	10209	8311	2.81%	3.81%						3.31%
2/3A	13906	11321	2.65%		5.10%					3.88%
2/3B	15251	12416	4.53%	5.52%	4.17%					4.74%
2/4A	16149	13147	1.02%	1.56%	2.32%					1.63%
2/4B	14803	12051	1.16%	0.97%	1.72%					1.28%
2/5A	13286	10816	0.40%	0.40%						0.40%
2/5E	18869	15361				0.93%				0.93%
2/5G	16720	13612				0.54%				0.54%
2/6A	21200	17259				0.17%	0.17%	0.28%		0.21%
2/6B	21200	17259				0.20%	0.18%	0.10%		0.16%
2/8C	16017	13039				0.55%	0.70%			0.62%
2/8D	11286	9188				0.74%	0.89%			0.81%
2/9A	18600	15142				0.27%	0.15%	0.15%		0.19%
2/9B	21700	17666				0.21%	0.16%	0.18%	0.49%	0.26%
2/10B	16000	13026				0.26%	0.85%	0.41%		0.51%
2/10C	12470	10152				0.84%	1.35%	1.28%		1.16%
2/10D	14390	11715				1.85%	1.68%	1.53%		1.69%
Avg.			2.09%		3.33%			0.61%		1.34%

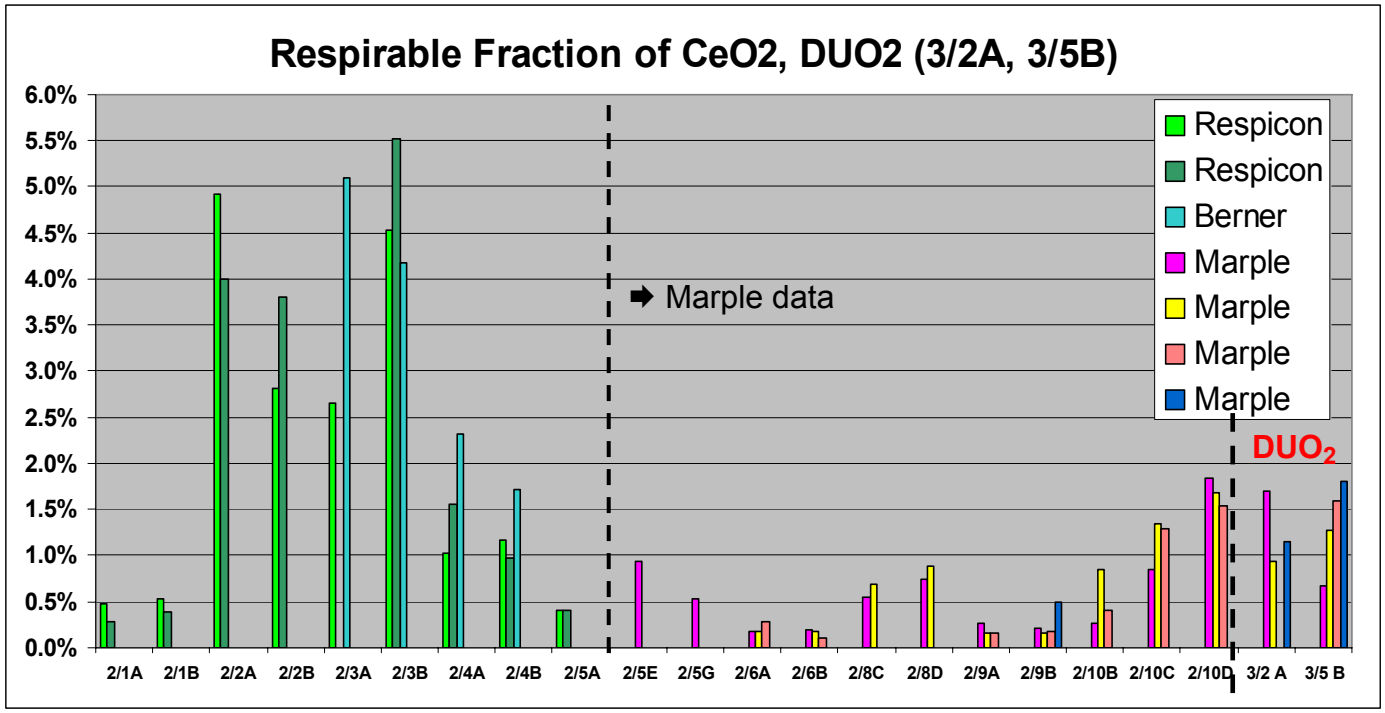


Figure 7.1 Phases 2, 2+, and 3 Test Results for CeO_2 and DUO_2 Respirable Fractions

For example a log normal distribution with a mean of 500 micrometers and a geometric standard deviation of 6 has 1.45% of the distribution below 10 micrometers. If the mean is increased by 10% and the standard deviation is decreased by 10%, 0.89% of the distribution is below 10 micrometers, a 40% reduction in RF. The variation in the particulated distribution of the CeO_2 matrix material is larger than 10%. Thus, considerable variation in the respirable fraction for CeO_2 may be expected from test to test. Furthermore, within a given test, a contribution to variation will be made by the small amount of material in this size range and the possible inhomogeneity in the small amount of aerosol sampled.

Several observations or implied results also may be made by comparing the assorted CeO_2 RF results grouped by test series, as shown in Figure 7.1.

Rodlet Pressurization Effects: Tests 2/6A and 2/6B were performed [Molecke et al., 2005a] with internally pressurized rodlets, at 27.6 bar and 40 bar, respectively. Compared to tests 2/9A and 2/9B, performed with non-pressurized rodlets (1 bar, atmospheric pressure) in a similar vertical explosive-aerosol test chamber, no discernable effect of rodlet pressurization can be noticed. Adding other test results into this comparison from other non-pressurized rodlets in tests 2/5A, 2/5E, 2/5G, 2/8C and 2/8D, all performed in the identical chamber as 2/6A and 2/6B, no specific effect of pressurization can be obtained among the various tests. Similar results were obtained with the first two Phase 3 DUO_2 tests, test 3/2 (A) at atmospheric pressure and test 3/5 (B) with 40 bar of He gas within the rodlet. The measured DUO_2 respirable fractions for these two tests, shown in Figure 7.1, are essentially the same, regardless of pressure within. The conclusion here is that the *internal pressurization effect in the plenum region of short* test rodlets (from 1 to 40 bars) is not a significant variable when compared to the total amount of particulates released from a relatively large (~27 mm) length of the rod impacted/particulated by the CSC jet. The measured differences between results from multiple, replicate Marples impactors used on individual tests appear greater than the differences between non-pressurized and pressurized rodlet versions of several comparable tests. That is, the potential effects due from short rodlet pressurization in these tests seem to be smaller than test-to-test and sample-to-sample variations. R. Einziger [Einziger, 2006] does not believe that the internal pressure is significant in these aerosol-explosive tests because we blow a "large" ~27 mm-long hole in a rodlet sample with less than 68 mm of (surrogate) fuel. He considers that the effects of internal pressure driving out small particles of fuel will be insignificant. However, for a long, fuel-length rod, which develops a crack too small for fuel to be dispersed, Einziger also believes that the internal pressure will drive out some fuel-rim particles and fission products. NOTE: Based on these experimental results and opinions, short spent fuel test rodlets for Phase 4 testing will, with WGSTSC concurrence, be fabricated without internal pressurization, i.e., with 1 bar He gas; refer to Section 8.4.

It is also difficult to discern any significant effects on measured CeO_2 respirable fraction produced when comparing results from a sealed, vertical test chamber (tests 2/5E through 2/9B) with results from semi-open chambers (tests 2/10B through 2/10D) plus similar semi-open square box chamber (tests 2/4A and 2/4B) or vented test 2/5A. The areas of concern between these different test configurations are potential effects of explosive byproduct carbon soot and chamber temperature rise (thermophoretic effects), from the HEDD detonation. However, RF results from tests 2/10B and 2/10C plus 2/10D do vary by a factor of X2-X3. It may be possible to attribute the somewhat larger measured RF values in 2/10C and 2/10D to the lower-density central doped CeO_2 pellets used; refer to Table 4.1.

7.2 Aerosol Results for Zirconium

Table 7.2 presents the respirable fraction results (for particles of size ≤ 10 μm AED) for zirconium, from the Zircaloy-4 cladding tube; Figure 7.2 illustrates this zirconium data. The amount of zirconium material dispersed is based on the observed gap in the target rodlet. The results for two Phase 3 tests also have been included in the table and figure.

The calculated zirconium respirable fraction average was 1.35 ± 0.31 % of dispersed mass based on all collected data (with a 99% confidence interval); the respirable fraction average was 1.23 ± 0. 29 % based on the Marple data only. These values are comparable to the cerium oxide respirable fractions measured for all data. Zirconium (Zircaloy 4 cladding) is a ductile metal, not a brittle ceramic like the CeO_2 ceramic pellets. The zirconium tube was also disrupted by the HEDD jet and fragmentation may also be dominated by mechanical disruption. However, the zirconium can partially melt and oxidize as a result of the HEDD jet impact. High speed video photography was performed during tests 2/0, 2/1A, and 2/1B [Molecke et al., 2004a]. Rapid oxidation (burning) of the zirconium was clearly evident, occurring within the first ~ 0.3 seconds after detonation. Zirconium oxidation is also suggested by the appreciable amount of zirconium found in the smaller, respirable impactor size ranges.

From observations of the Marple impactor zirconium distributions in the ~ 0 through 10 μm AED respirable size range, and even up to ~ 35 μm, (as illustrated in multiple figures in Appendix A) zirconium is not one of the most prevalent respirable materials produced by the CSC jet explosive impact process. However, zirconium particles appear to peak somewhat over the respirable range size of 1.6 to 10 μm AED (maximized, frequently, at about 1.6 to 6 μm AED). The measured concentrations for copper particles are significantly greater then those for zirconium particles, but the copper particles appear to peak over the entire respirable size range of 0 to 10 μm AED.

Table 7.2 Phase 2, 2+ and Phase 3 Test Results for Zirconium Respirable Fraction

	Zr Dispersed	Zirconium Respirable Fraction (%)							
Test	Zr (mg)	Respicon	Respicon	Berner	Marple	Marple	Marple	Marple	Test Avg
2/1A	2990	0.41%	0.21%						0.31%
2/1B	2990	0.28%	0.26%						0.27%
2/2A	3035	1.85%	1.61%						1.73%
2/2B	3002	1.48%	1.94%						1.71%
2/3A	3249	1.89%		4.87%					3.38%
2/3B	3249	2.23%	2.61%	3.04%					2.63%
2/4A	3769	0.84%	1.17%	3.45%					1.82%
2/4B	3249	1.10%	0.90%	2.95%					1.65%
2/5A	3509	1.18%	1.34%						1.26%
2/5E	2859				2.92%				2.92%
2/5G	3249				1.29%				1.29%
2/6A	3510				1.12%	1.30%	1.27%		1.23%
2/6B	3510				1.24%	1.39%	1.44%		1.36%
2/8C	2989				1.32%	2.12%			1.72%
2/8D	2729				2.08%	2.35%			2.22%
2/9A	3930				0.58%	0.79%	0.51%		0.63%
2/9B	3280				1.78%	1.52%	1.63%	1.31%	1.56%
2/10B	3930				0.62%	0.76%	0.64%		0.67%
2/10C	2900				0.72%	0.80%	0.85%		0.79%
2/10D	3670				0.81%	0.69%	0.67%		0.72%
avg all		1.25%		3.58%			1.23%		1.43%
Test	Zr (mg)	Respicon	Respicon	Berner	Marple	Marple	Marple	Marple	Test Avg
3/2A	3540				1.09%	0.81%		0.82%	0.909%
3/5B	3900				0.32%	0.61%	0.71%	0.93%	0.640%

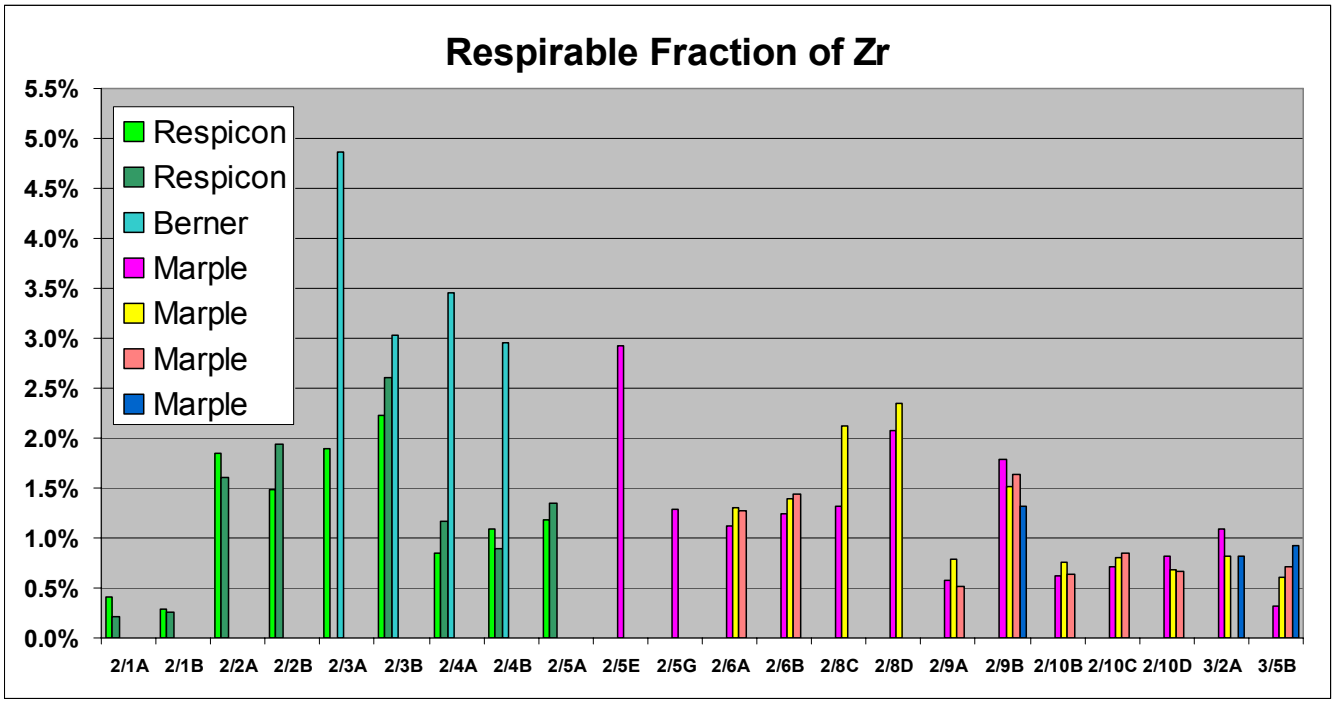


Figure 7.2 Phase 2, 2+ and Phase 3 Test Results for Zirconium Respirable Fraction

7.3 Aerosol Results for Fission Product Dopant Cesium

Table 7.3 presents the respirable fraction results for fission product dopant cesium, both for previous Phase 2 tests that incorporated dopants [Molecke et al., 2005a] and the new Phase 2+ tests. Figure 7.3 illustrates all the cesium RF data in Table 7.3.

Table 7.3 Phase 2 and 2+ Test Results for Cesium Dopant Respirable Fraction

	CsI Dispersed		Cesium Respirable Fraction (%)						
Test	CsI (mg)	Cs(mg)	Respicon 1	Respicon 2	Berner	Marple 1	Marple 2	Marple 3	Test Avg
2/4A	32.6	16.7	24.40%	32.39%	10.34%				22.38%
2/4B	30.4	15.5	23.17%	16.91%	11.63%				17.23%
2/5A	31.0	15.9	28.50%	28.22%					28.36%
2/5E	22.6	11.6				42.44%			42.44%
2/5G	18.9	9.7				27.40%			27.40%
2/6A	30.2	15.4				17.16%	20.96%	22.26%	20.13%
2/6B	35.8	18.3				26.72%	28.12%	36.84%	30.56%
2/8C	33.9	17.3				41.88%	72.87%		57.37%
2/8D	33.9	17.3				44.86%	46.42%		45.64%
2/10B	98.8	50.5				16.30	25.77	26.84%	22.97%
2/10C	217	111				14.54	30.29	24.10%	22.98%
2/10D	217	111				24.42	23.19	20.39%	22.67%
Avg all			25.60%		10.99%			30.18%	27.91%

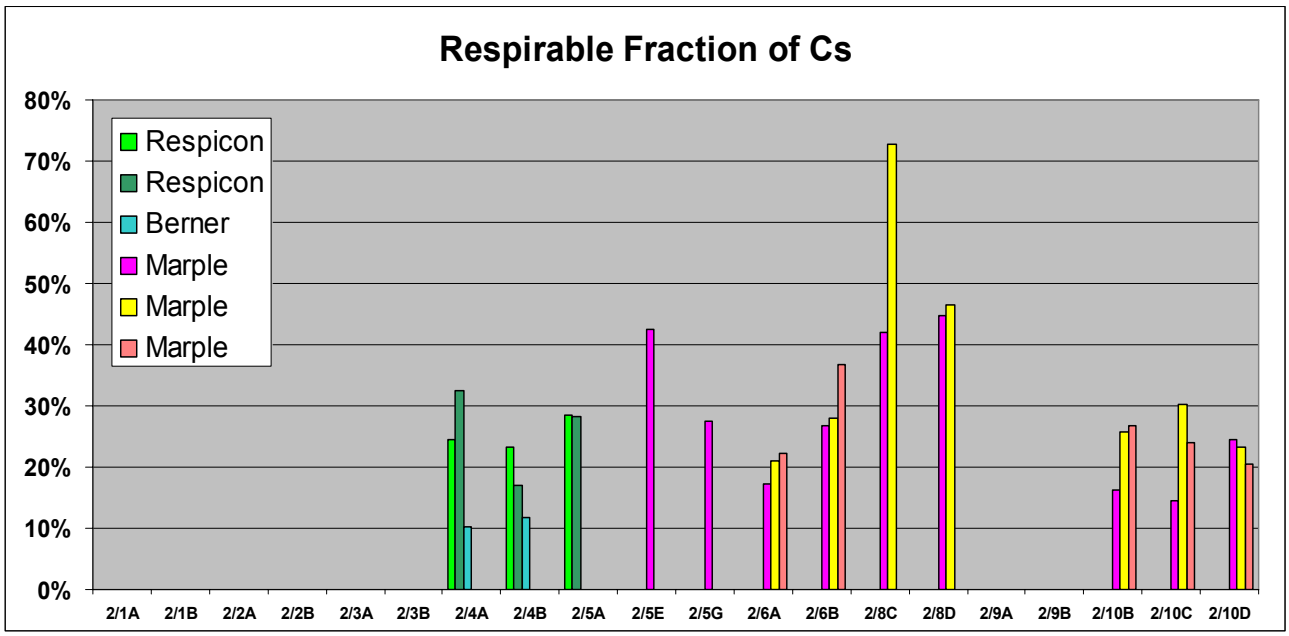


Figure 7.3 Phase 2 and 2+ Test Results for Cesium Dopant Respirable Fraction

There is *no observed significant difference* in the measured cesium respirable fraction results shown in Figure 7.3, above, between the physical forms of the dopant material used, whether in external, non-homogeneous solid chemical wells or resin-based disks, or more nearly homogeneous distribution of these dopants within the cerium oxide pellet- - similar to the situation expected in actual spent fuel, irradiated UO_2 pellets. (There are, however, noticeable differences for measured cesium enrichment factors, EF, to be discussed, following.) There is also no observable, significant difference between closely matched Phase 2+ test 2/10B (with six, external dopant disks) and tests 2/10C and 2/10D (with the internally doped cerium oxide pellets). All of the fission product material in all test cases was within the CSC jet particulated zone.

From observations of the Marple impactor data in tests 2/10B-D for cesium respirable particle size distributions (as illustrated in multiple figures in Appendix A), cesium particle distributions appear to peak over the respirable range size between 0.5 to 3.5 µm AED. No distinct cerium particle pattern is observed in the aerosol range from about 30 to 100 µm AED, collected with the LPS apparatus. The cesium particle distribution in the aerosol range from about 30 to 100 µm AED, collected with the LPS apparatus, is generally highest in the 30-48 µm segment, then decreases.

The cesium iodide used as a non-radioactive fission dopant in these surrogate material tests melts at 899 ºK (626 ºC) and boils at 1553 ºK. It may undergo phase changes and volatilization when impacted by the CSC jet. Based on the observed Marple data cesium peak at 0.5-3.5 µm AED, it is obvious that thermally volatilized cesium is preferentially found sorbed onto respirable particles, particularly in the 0.5 to 3.5 µm AED size range, correlating well with the distribution of copper and soot.

The higher observed values for cesium respirable fractions (compared to the cerium oxide pellet material) indicate that the cesium is enriched in the smaller-sized particle range. An enrichment factor (EF) for the cesium respirable fraction is *defined as the ratio of cesium to cerium in the particles below 10 micrometers AED divided by the ratio of cesium to cerium dispersed into the*

chamber. As defined, the enrichment factor is also equal to the respirable fraction of Cs divided by the respirable fraction of Ce. The measured/calculated cesium enrichment factors for all Phase 2 and 2+ tests are listed in Table 7.4 and plotted in Figure 7.4. Since the Enrichment Factor is based on *ratios*, it is less subject to uncertainties and sampling losses, such as potential thermophoretic and diffusiophoretic deposition effects, than are respirable fraction determinations.

The respirable cesium fission product enrichment factor, EF, is 64 +/- 34 of dispersed respirable particle masses in the 0 to 10 µm AED size range, based on all data in Table 7.4. The enrichment factor is similarly, 79 +/- 45 based on Marple impactor data only; all results are reported at the 99% confidence interval.

Table 7.4 Phase 2 and 2+ Test Results for Cesium Dopant Enrichment Factor

	Dispersed Mass		Cesium Enrichment Factor						
Test	Cs (mg)	Ce (mg)	Respicon	Respicon	Berner	Marple	Marple	Marple	Test Avg
2/4A	16.7	13147	23.9	20.7	4.5				16.4
2/4B	15.5	12051	19.9	17.5	6.8				14.7
2/5A	15.9	10816	70.8	69.9					70.4
2/5E	11.6	15361				45.6			45.6
2/5G	9.7	13612				50.8			50.8
2/6A	15.4	17259				101.8	123.0	79.0	101.3
2/6B	18.3	17259				132.7	155.8	369.4	219.3
2/8C	17.3	13039				76.7	104.2		90.4
2/8D	17.3	9188				60.8	52.3		56.6
2/10B	50.5	13026				63.2	30.3	65.9	53.1
2/10C	111.0	10152				17.2	22.5	18.8	19.5
2/10D	111.0	11715				13.2	13.8	13.3	13.4
avg all			37.1		5.6			76.7	63.6
2/7B		(glass)						84	
2/10E		(glass)						11.5	
2/10F		(glass)						7.1	

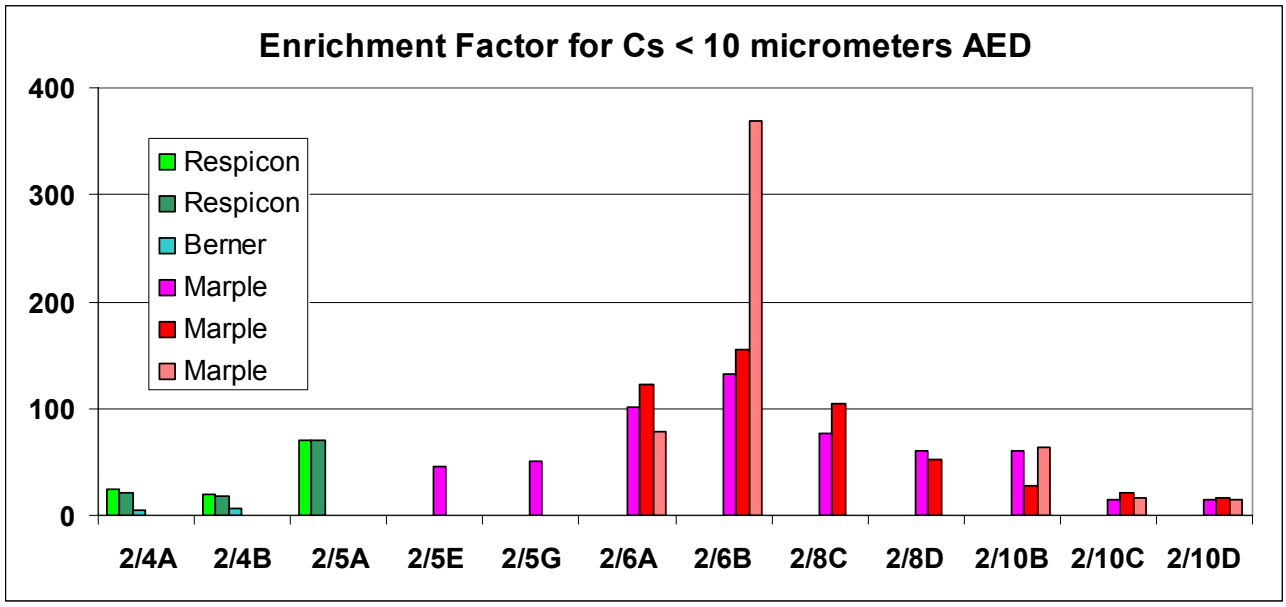


Figure 7.4 Phase 2 and 2+ Test Results for Cesium Dopant Enrichment Factor

Based on the results in Figure 7.4, there were some observed differences in the measured cesium EF results between the physical forms of the dopant material used, whether located in external, non-homogeneous solid chemical wells in the pellets, or adjacent resin-based disks, or in a more nearly homogeneous distribution of these dopants within the CeO_2 pellets -- similar to the situation expected for fission products in actual spent fuel, irradiated UO_2 pellets. Recent cesium EF data from Phase 2+ tests with doped cerium oxide pellets (tests 2/10C and 2/10D) and doped German HAW glass surrogate indicate lower EF values for Cs in the partially vented chamber with an external detonation of the HEDD compared to the closed test chamber with internal detonation (Phase 2 and 3 tests), with more carbon soot present and with higher chamber gas temperatures.

It is difficult to make conclusions on any significant effects on measured respirable cesium enhancement factor as a function of homogeneous or non-homogeneous fission product material distribution in the test rodlets. It does appear that the measured cesium EF for tests 2/10C and 2/10D, with the CsI thermally diffused through, nearly homogeneously within the base CeO_2 pellets, are lower in magnitude compared to tests 2/5E through 2/10B, with non-homogeneous fission product dopant disks. However, cesium enrichment factors for tests 2/10C and 2/10D, 17.7 and 15.7, respectively, are nearly identical to those measured in similar (semi-open square box chamber) tests 2/4A and 2/4B, 16.4 and 14.7, respectively, where the fission product CsI material was in a discrete well drilled into the center pellet. This would also support the interpretation that there is in fact a significant difference between fission product enrichment in a semi-open chamber compared to a closed chamber with inside HEDD detonation. These preliminary findings will be investigated further after completion of Phase 2+ with the forthcoming tests of Phase 2+ 2/10G and 2/10H using homogenously doped cerium oxide pellets in a German semi-open chamber setup.

Some further indications on the impact of the experimental setup on fission product enrichment are already available from the analysis of tests 2/10E and 2/10F with surrogate HLW glass pellets, performed in the semi-open Phase 2+ test chamber. The measured cesium EF for tests 2/10E and 2/10F, integrated over the respirable range of 0-10 µm AED, were 11.5 and 7.1, respectively (average 9.3). In direct comparison with test 2/7B performed in the closed, Phase 2 aerosol-explosive chamber, the measured cesium EF was 84; this is a reduction by a factor of 9.

The enrichment factor definition can also be applied as a differential, particle size-dependent enrichment factor. Cesium EF, plotted and listed as a function of particle-size, are illustrated in Figures 7.5 through 7.13 and Tables 7.5 through 7.13, for Phase 2 and 2+ tests 2/6A and 6B, 2/7B, 2/8C and 8D, and 2/10B, 10C, 10D, and 10E/10F, respectively. Particle data are included from Marple impactors, Large Particle Separators, and mechanically sieved particle debris.
NOTE: In the following tables, DpMID = Diameter of particle, mid-point.

In all the data presented, EF is quite high for particles less than 10 micrometers in aerodynamic diameter; the distributions below 10 micrometers are very similar among all the data in that the EF values are generally at 100 to 200 up to about 1 to 2 micrometers and then fall to about 3 at 10 micrometers. In the data for all but test 2/7B there appears to be a slight increase in EF in sizes larger than 10 micrometers. However this may be an *artifact* in that it is seen only in the analysis of the Stage 0 impactor data and the Large Particle Separator. In the tests in which the debris analysis is presented (2/6A, 6B and 2/8C, 8D), the EF is generally less than 1 and does not have a peak. The debris size is physical or sieve size and would be shifted to a larger size by a factor of about 2.5 to

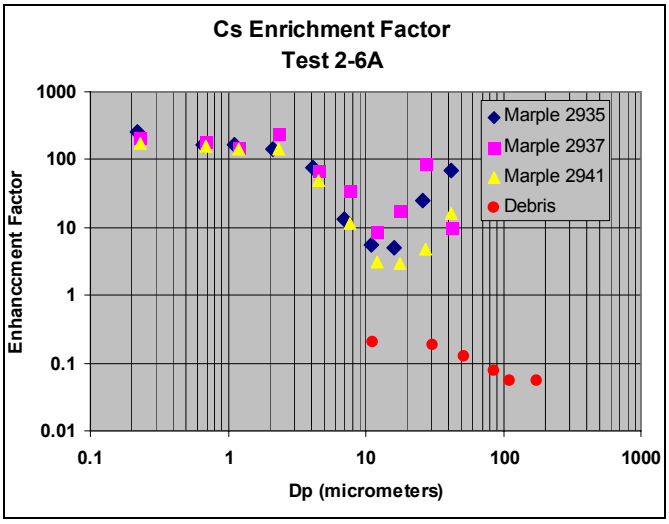


Figure 7.5 Differential Cesium EF, Test 2/6A

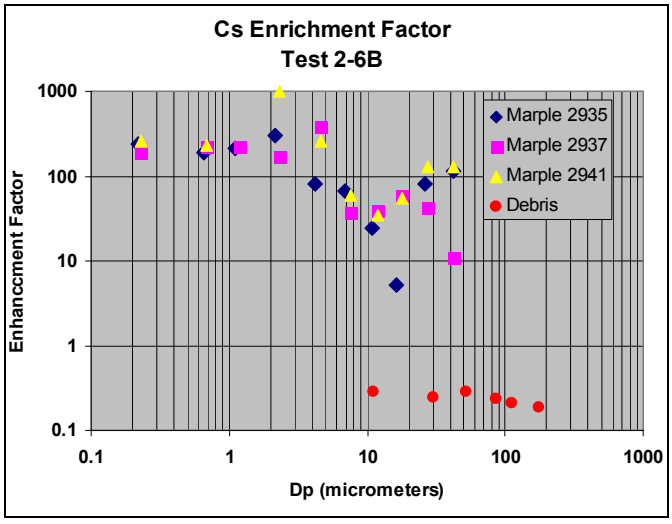


Figure 7.6 Differential Cesium EF, Test 2/6B

Test	Sampler	Test	Sampler	Test	Sampler	Test	Sampler
2-6A	Marple 2935	**2-6A**	Marple 2937	**2-6A**	Marple 2941	**2-6A**	Debris
DpMID	**EF**	DpMID	**EF**	DpMID	**EF**	DpMID	**EF**
microns	**Cs**	microns	**Cs**	microns	**Cs**	microns	**Cs**
0.22	**252.4**	0.23	**216.3**	0.23	**178.2**	11.2	**0.20**
0.65	**162.3**	0.70	**180.3**	0.70	**159.4**	30.4	**0.18**
1.11	**162.8**	1.20	**149.0**	1.20	**143.0**	52.3	**0.13**
2.14	**145.0**	2.33	**241.1**	2.33	**143.4**	86.0	**0.08**
4.18	**74.6**	4.58	**67.7**	4.58	**48.2**	111.8	**0.06**
6.98	**13.5**	7.67	**35.6**	7.67	**11.6**	176.8	**0.05**
10.94	**5.5**	12.04	**8.7**	12.04	**3.1**		
16.12	**4.9**	17.75	**17.7**	17.75	**3.0**		
26.0	**25.2**	27.3	**86.2**	27.3	**4.7**		
41.8	**70.2**	41.8	**9.8**	41.8	**16.3**		

Table 7.5 Differential Cesium EF, Test 2/6A

Test	Sampler	Test	Sampler	Test	Sampler	Test	Sampler
2-6B	Marple 2935	**2-6B**	Marple 2937	**2-6B**	Marple 2941	**2-6B**	Debris
DpMID	**EF**	DpMID	**EF**	DpMID	**EF**	DpMID	**EF**
microns	**Cs**	microns	**Cs**	microns	**Cs**	microns	**Cs**
0.22	**235.2**	0.23	**192.6**	0.23	**253.9**	11.2	**0.28**
0.65	**186.2**	0.70	**219.8**	0.70	**229.6**	30.4	**0.24**
1.11	**214.4**	1.20	**218.4**	1.20	**1326.6**	52.3	**0.29**
2.14	**304.7**	2.33	**168.3**	2.33	**1005.5**	86.0	**0.23**
4.18	**82.3**	4.58	**376.6**	4.58	**256.5**	111.8	**0.21**
6.98	**67.7**	7.67	**36.6**	7.67	**60.4**	176.8	**0.18**
10.94	**24.6**	12.04	**38.9**	12.04	**34.2**		
16.12	**5.2**	17.75	**0.0**	17.75	**55.2**		
26.0	**80.8**	27.3	**41.8**	27.3	**127.7**		
41.8	**114.6**	41.8	**10.8**	41.8	**127.7**		

Table 7.6 Differential Cesium EF, Test 2/6B

be comparable to the aerodynamic diameter from the impactors. Even so, we see some overlap between the impactor data and the debris data which indicate that the upswing in EF at sizes larger that 10 micrometers aerodynamic diameter suggested by the impactor and LPS data may be an artifact of measurement.

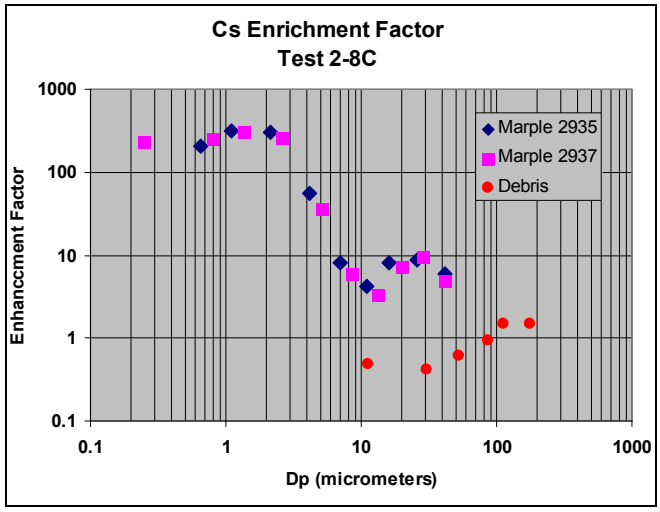


Figure 7.7 Differential Cesium EF, Test 2/8C

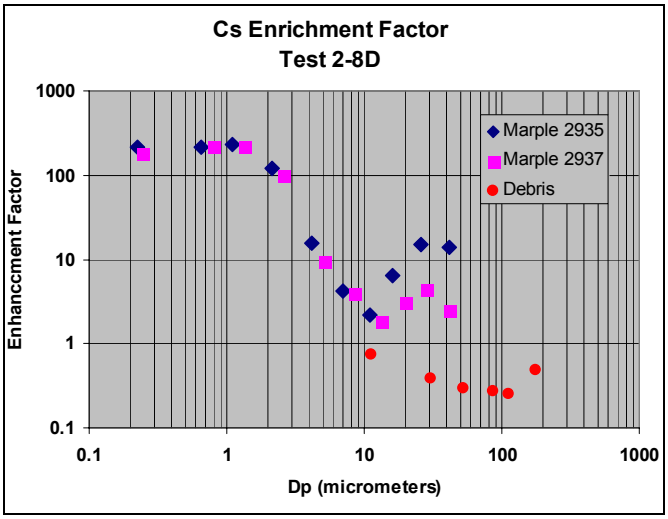


Figure 7.8 Differential Cesium EF, Test 2/8D

Test	Sampler	Test	Sampler	Test	Sampler
2-8C	Marple 2935	**2-8C**	Marple 2937	**2-8C**	Debris
DpMID	**EF**	DpMID	**EF**	DpMID	**EF**
microns	**Cs**	microns	**Cs**	microns	**Cs**
0.22	**0.0**	0.25	**235.0**	11.2	**0.49**
0.65	**206.2**	0.80	**250.6**	30.4	**0.41**
1.11	**318.1**	1.36	**302.2**	52.3	**0.60**
2.14	**298.2**	2.61	**255.8**	86.0	**0.94**
4.18	**56.2**	5.10	**36.8**	111.8	**1.48**
6.98	**8.2**	8.52	**5.9**	176.8	**1.49**
10.94	**4.1**	13.36	**3.3**		
16.12	**8.2**	19.68	**7.3**		
26.0	**8.7**	28.7	**9.6**		
41.8	**5.8**	41.8	**4.9**		

Table 7.7 Differential Cesium EF, Test 2/8C

Test	Sampler	Test	Sampler	Test	Sampler
2-8D	Marple 2935	**2-8D**	Marple 2937	**2-8D**	Debris
DpMID	**EF**	DpMID	**EF**	DpMID	**EF**
microns	**Cs**	microns	**Cs**	microns	**Cs**
0.22	**211.9**	0.25	**176.6**	11.2	**0.75**
0.65	**214.9**	0.80	**211.9**	30.4	**0.39**
1.11	**227.6**	1.36	**211.9**	52.3	**0.30**
2.14	**120.5**	2.61	**100.5**	86.0	**0.27**
4.18	**15.6**	5.10	**9.6**	111.8	**0.25**
6.98	**4.2**	8.52	**3.9**	176.8	**0.49**
10.94	**2.2**	13.36	**1.8**		
16.12	**6.3**	19.68	**3.0**		
26.0	**15.0**	28.7	**4.3**		
41.8	**14.1**	41.8	**2.4**		

Table 7.8 Differential Cesium EF, Test 2/8D

Test¤	Sampler¤	Test¤	Sampler¤	Test¤	Sampler¤
2-10B¤	Marple 002¤	**2-10B¤**	Marple 003¤	**2-10B¤**	Marple 005¤
DpMID¤	EF¤	DpMID¤	EF¤	DpMID¤	EF¤
microns¤	Cs¤	microns¤	Cs¤	microns¤	Cs¤
0.25¤	**438.9¤**	0.24¤	**237.3¤**	0.24¤	**219.3¤**
0.83¤	**204.7¤**	0.77¤	**150.0¤**	0.77¤	**188.2¤**
1.39¤	**91.7¤**	1.29¤	**390.4¤**	1.28¤	**625.3¤**
2.63¤	**34.5¤**	2.44¤	**462.9¤**	2.43¤	**544.2¤**
5.11¤	**15.3¤**	4.75¤	**291.4¤**	4.73¤	**369.5¤**
8.50¤	**5.8¤**	7.90¤	**4.9¤**	7.87¤	**5.7¤**
13.31¤	**4.4¤**	12.38¤	**3.2¤**	12.32¤	**4.1¤**
19.59¤	**8.71¤**	18.22¤	**6.8¤**	18.14¤	**8.7¤**
28.67¤	**13.35¤**	27.65¤	**311.63¤**	27.59¤	**283.47¤**
41.83¤	**13.71¤**	41.83¤	**317.67¤**	41.83¤	**17.68¤**
59.16¤	**4.48¤**	59.16¤	**12.18¤**	59.16¤	**29.85¤**

Table 7.9 Differential Cesium EF, Test 2/10B

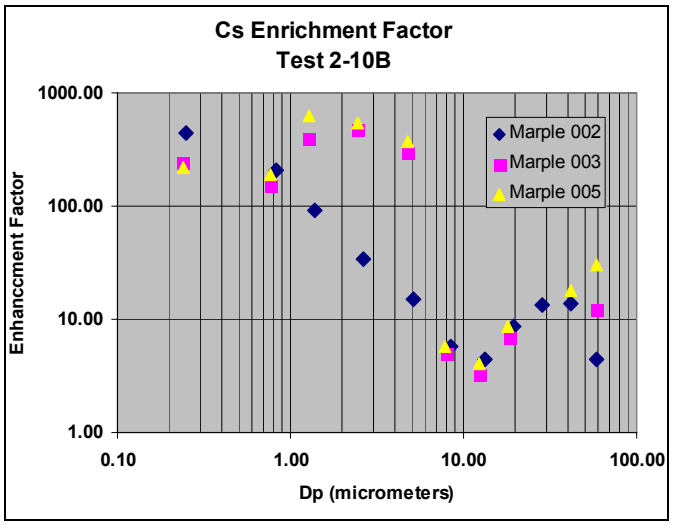


Figure 7.9 Differential Cesium EF, Test 2/10B

Test¤	Sampler¤	Test¤	Sampler¤	Test¤	Sampler¤
2-10C¤	Marple 002¤	**2-10C¤**	Marple 005¤	**2-10C¤**	Marple 006¤
DpMID¤	EF¤	DpMID¤	EF¤	DpMID¤	EF¤
microns¤	Cs¤	microns¤	Cs¤	microns¤	Cs¤
0.25¤	**141.2¤**	0.24¤	**149.4¤**	0.25¤	**153.2¤**
0.83¤	**120.4¤**	0.77¤	**156.7¤**	0.82¤	**148.5¤**
1.39¤	**38.1¤**	1.29¤	**109.3¤**	1.37¤	**76.6¤**
2.63¤	**12.5¤**	2.45¤	**36.7¤**	2.60¤	**17.1¤**
5.11¤	**5.4¤**	4.75¤	**8.9¤**	5.05¤	**5.7¤**
8.50¤	**3.2¤**	7.91¤	**4.3¤**	8.41¤	**4.0¤**
13.31¤	**2.6¤**	12.38¤	**3.6¤**	13.18¤	**3.6¤**
19.59¤	**5.21¤**	18.23¤	**4.0¤**	19.39¤	**5.1¤**
28.67¤	**7.72¤**	27.66¤	**16.88¤**	28.53¤	**10.14¤**
41.83¤	**8.15¤**	41.83¤	**9.00¤**	41.83¤	**10.33¤**
59.16¤	**4.11¤**	59.16¤	**2.07¤**	59.16¤	**2.58¤**

Table 7.10 Differential Cesium EF, Test 2/10C

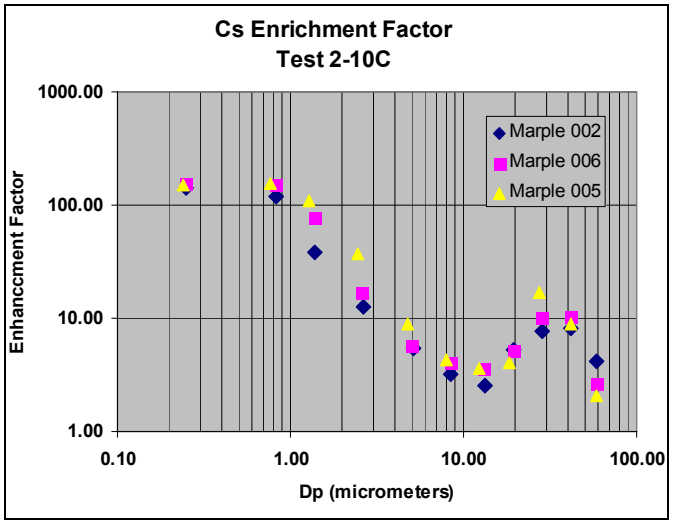


Figure 7.10 Differential Cesium EF, Test 2/10C

Test¤	Sampler¤	Test¤	Sampler¤	Test¤	Sampler¤
2-10D¤	Marple 003¤	**2-10D¤**	Marple 005¤	**2-10D¤**	Marple 006¤
DpMID¤	EF¤	DpMID¤	EF¤	DpMID¤	EF¤
microns¤	Cs¤	microns¤	Cs¤	microns¤	Cs¤
0.24¤	**162.7¤**	0.24¤	**201.0¤**	0.25¤	**181.3¤**
0.77¤	**210.4¤**	0.77¤	**229.7¤**	0.81¤	**178.5¤**
1.29¤	**132.1¤**	1.29¤	**136.8¤**	1.36¤	**76.9¤**
2.46¤	**55.3¤**	2.44¤	**69.6¤**	2.58¤	**15.1¤**
4.77¤	**7.6¤**	4.75¤	**8.9¤**	5.02¤	**5.9¤**
7.94¤	**2.8¤**	7.90¤	**3.4¤**	8.35¤	**3.5¤**
12.43¤	**2.3¤**	12.37¤	**2.2¤**	13.08¤	**3.7¤**
18.30¤	**3.07¤**	18.21¤	**3.4¤**	19.25¤	**3.6¤**
27.71¤	**6.74¤**	27.65¤	**5.66¤**	28.42¤	**8.71¤**
41.83¤	**7.64¤**	41.83¤	**7.21¤**	41.83¤	**8.03¤**
59.16¤	**1.40¤**	59.16¤	**1.38¤**	59.16¤	**1.89¤**

Table 7.11 Differential Cesium EF, Test 2/10D

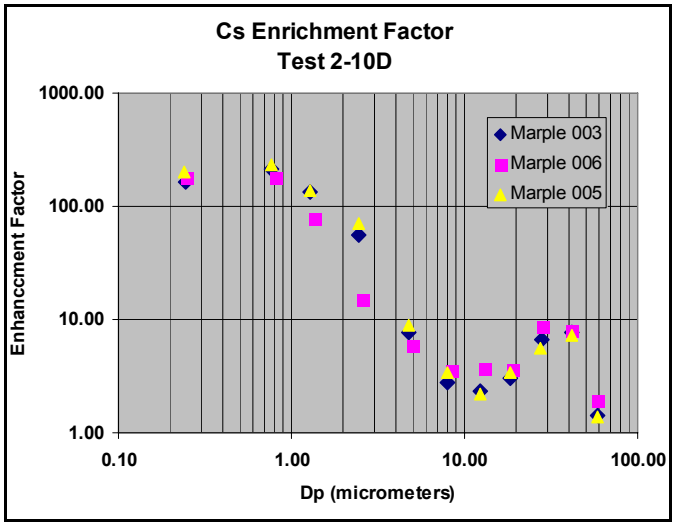


Figure 7.11 Differential Cesium EF, Test 2/10D

Size range [µm]	IEF ITEM/EMI	IEF SNL/ITEM
< 1.4	56	461
< 10	4.4	84

Table 7.12 Differential Cesium EF on Glass, Test 2/7B

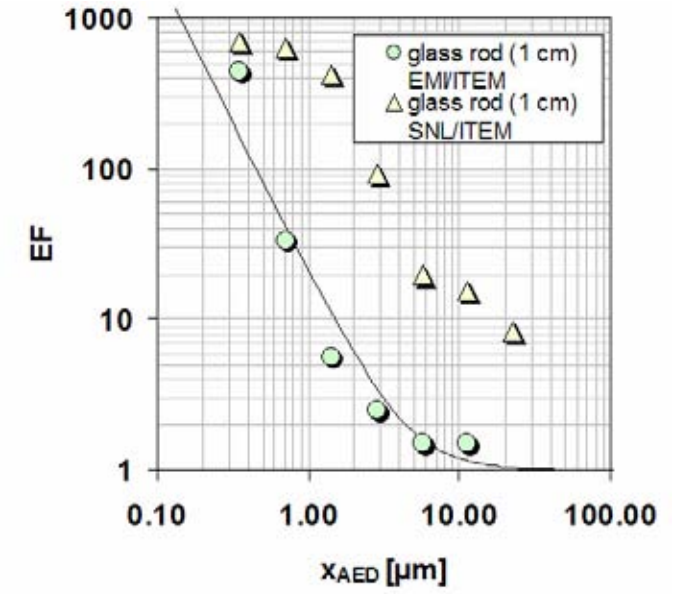


Figure 7.12 Differential Cesium EF on Glass, Test 2/7B

size range [µm]	IEF 2-10 E	IEF 2-10 F	IEF ITEM/EMI
< 1.4	19.1	12.1	56
< 10	11.5	7.1	4.4

Table 7.13 Differential Cesium EF on Glass, Test 2/10E and 10F

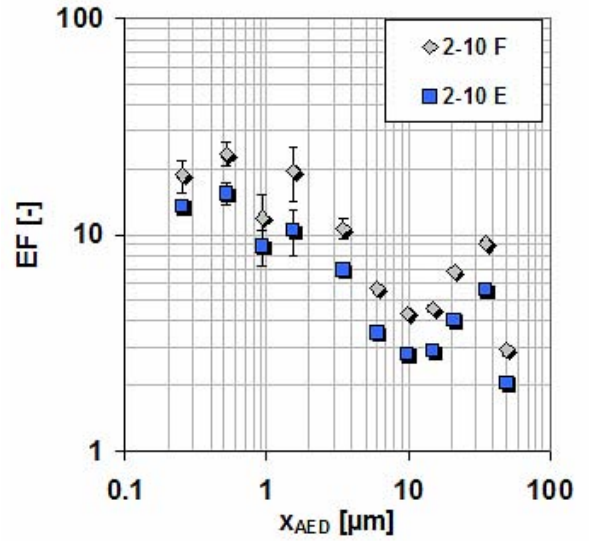


Figure 7.13 Differential Cesium EF, Test 2/10E, 10F

There may be two effects going on in regards to the large variations observed in cesium EF values. There is reason to believe that the mechanism producing the cesium particle distribution (Cs vaporization and subsequent condensation on the smaller sized particles, most probably soot) is not necessarily related to that producing the cerium, surrogate material particle distribution (mechanical shock and fragmentation of a brittle material into small particles). While the EF is a measurement that can be made with good precision in a given size range (the sampling efficiencies cancel nicely), the value in a given test can vary considerably. This is true especially since the mechanical fragmentation particles in the small size range are the tail of the larger distribution. While the larger particle distribution can be very repeatable, the tails can vary considerably. Consider that the mass fraction of cerium oxide less than 10 micrometers aerodynamic diameter is only a few percent of the fragmented cerium oxide and that it will vary from test to test as we have seen and discussed above. Slight changes in the CeO_2 particle distribution can produce considerable changes in the distribution in the small tail of the distribution. This variation, coupled with a separate source of variation in the soot distribution and amount of Cs available gives two separate particle distributions that we then ratio to get the Cs EF. Given all these sources of variability in EF, it is somewhat remarkable that we see such similarity in the size dependent EF plots. Comparison of the results of two different experiments will be affected by the specific conditions in each. Comparison of data between tests using glass rods and those using CeO_2 pellets must consider the different fragmentation behavior of each as it affects the RF and EF. It is interesting to note that the EF for the Cs in the glass tests 2/10E and2/10F displays similar behavior to the CeO_2 tests, but has much lower EF values for the particles on the order of 2 micrometers and less. This may be from a difference in the fragmentation behavior between the glass and CeO_2 pellets used in the tests.

The observed differences in Cs enrichment factors seen between the German (EMI/ITEM) and the Sandia (SNL/ITEM) tests are of similar interest. Possible reasons for these observed differences may be due to different temperatures in the respective test aerosol collection chambers, with significantly higher temperatures within the SNL test chamber, or differences in the fragmentation of the target giving perhaps more sub-10 μm matrix particles in the German test (lower enrichment values). However, the tests 2/10E and 2/10F conducted at SNL with glass rods yielded lower Cs EF, more consistent with the German EMI/ITEM test. The differences in these ITEM results are not believed to arise from sampling or analysis as we have previously reported [Molecke et al., 2005a] excellent agreement between the Berner impactor with samples analyzed in Germany and the Marple impactor with samples analyzed in the USA for test 2/7B.

Further analysis of the fission product enhancement results, and possibly future supplemental testing, will need to be made to evaluate the effects of high temperature within the aerosol collection chamber on the sampling. Tests to determine the temperature and pressure in the closed chamber tests yielded peak pressures of about 65 to 70 psia (4.5 – 5.22 bars) and peak gas temperatures on the order of 900 – 1000 ºC (1200 to 1300 K) at more than 3 seconds after detonation. As discussed previously, the temperature in the vertical aerosol test chamber could be considerably higher immediately after detonation. It is possible that the higher temperatures seen in the vertical test chamber over the first couple of seconds could have caused considerable cesium vaporization. In the cooling environment, the cesium vapor would condense out either as small Cs particles or, in the presence of the high aerosol surface area presented by the soot, onto pre-existing or forming or condensing soot particles. Copper may play a role in this process by also condensing out on soot particles or by participation in the

formation of particles with the soot that acts to preferentially collect the cesium. In the tests reported by the German partners (ITEM/EMI), the lower temperatures may have resulted in less cesium vaporization from the glass rodlets and less soot may have been available for vapor condensation. The role of copper may be significant in this case; the copper may have formed a nucleation-condensation aerosol onto which cesium may have condensed or there may have been a binary nucleation- condensation process involving the copper and cesium.

Additional analysis of fragmentation behavior and debris distribution will need to be performed to ascertain the variation in the particle mass contained in the tails of the fragmented pellets.

7.4 Aerosol Results for Other Fission Product Dopants

The fission product dopants included in selected tests were cesium (in the form of CsI), strontium (in the form of SrO), ruthenium (in the form of RuO_2 and Ru metal in the doped pellets) and europium (in the form of Eu_2O_3). Refer to Section 4.2.1 for a complete description.

After all the Phase 2+ tests and the first Phase 3 test 3/5 (A) had been performed and the ICP-MS chemistry analyses were received, it became obvious that there were very high anomalous concentrations of barium, boron, and aluminum present (orders of magnitude too high), and a fairly high, almost constant concentration of strontium. Blank fiberglass filter media (Whatman 934AH filter rounds and strips) used in the Marple impactors and the LPS apparatus were sent to SNL analytical chemistry for "blank" background concentration checks. Results from these blank media were that the fiberglass media contained Ba at ~ 40k ppm, Zn at ~ 32k ppm, Al at ~ 30k ppm, B at ~29k ppm, and Sr concentrations at 150-160 ppm. The actual, measured concentrations of Ba, Zn, Al, B, and Sr, are reported in the data tables in Appendix A for tests 2/10A through 3/2 (A) with an asterisk (*), to indicate that this content originated as a filter media impurity.

The glass fiber filter media used as particle collection substrates in the Marple impactors and the Large Particle Separators presented a problem in that they contain background levels of some of the fission product dopants comparable to those released in the tests. This impurity concentration problem was most notable for Sr but may be in effect for Ru and Eu as well. The elemental analyses of several impactor media substrates used in testing are listed in Table 7.14. The three glass fiber substrates seem to present the greatest levels of background interference for Sr and Eu but not for Ce, U, Cs, or Ru. The quartz fiber substrates have very low background levels for all the elements of interest, but present a problem in use in that they are quite fragile and can breakup during the unloading process. This is especially difficult when unloading takes place in a glove box. The Mylar substrates, sprayed with a slight amount of Silicone to enhance particle retention, are very low in background levels and also very strong mechanically. Further discussions of background impurity effects are described below.

Whatman filters media used in older Phase 2 aerosol tests did not, apparently, have high levels of impurities. Apparently, a new supplier for media to SNL used different fiberglass content. Starting with the second Phase 3 DUO_2 test, 3/5 (B), we replaced the fiberglass filter rounds and strips with quartz fiber filter media, to eliminate impurity concerns associated with the fiberglass media. Starting with tests 3/1 (C), we switched to Mylar substrates. Also, we send "blind" filter media blanks to the analytical chemistry laboratory, along with the explosive-aerosol particle samples.

Table 7.14 Selected Elements and Impurities in Impactor Substrates, Mass (mg)

Blanks	Mylar	Mylar+ Silicone	SKC-Glass	Glass New	Glass Old	SKC-Quartz	Quartz-Old
Uranium	5.00E-06	5.00E-06	1.80E-05	1.30E-05	1.30E-05	5.00E-06	5.00E-06
Cerium	2.00E-05	2.00E-05	8.10E-05	8.60E-05	8.40E-05	2.00E-05	2.00E-05
Zirconium	1.63E-04	5.70E-05	2.79E-03	2.52E-03	2.53E-03	5.00E-05	6.40E-05
Copper	2.00E-05	2.00E-05	4.46E-04	5.37E-04	3.62E-04	2.00E-05	2.00E-05
Cesium	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05
Ruthenium	2.00E-05	2.00E-05	2.00E-05	2.00E-05	2.00E-05	2.00E-05	2.00E-05
Strontium	2.00E-04	2.00E-04	7.61E-03	7.30E-03	7.39E-03	2.00E-04	2.00E-04
Europium	2.00E-05	2.00E-05	3.70E-04	3.62E-04	3.56E-04	2.00E-05	2.00E-05

Ruthenium: Ruthenium fission product dopant respirable particle size distributions are quite similar to those for cesium, but at a lower concentration. Observations of the Marple impactor data in test 2/10B for ruthenium respirable particle size distributions (as illustrated in multiple figures in Appendix A), indicate that ruthenium particles appear to peak over the respirable range size of 1.6 to 3.5 µm AED, although they are found over the entire range of 0 to 10 µm. The ruthenium particle distribution in the aerosol range from about 30 to 100 µm AED, collected with the LPS apparatus, is generally highest in the 30-48 µm size range, then decreases. It seems obvious that thermally volatilized ruthenium, similar to the cesium, is preferentially found sorbed onto respirable particles, particularly in the 1.6 to 3.5 µm AED size range, correlating well with the distribution of copper and soot. Although the ruthenium collected in tests 2/10C and 2/10D is similar in amount and distribution to that seen in 2/10B, the amount detected is much larger than the amount placed in the test as dopant. As listed in Table 7.14, impurity levels for Ru in the collection substrates used are at the limit of detectability. Consequently, it is not expected that background interference or impurities in the samples would lead to these detection levels in tests 2/10C and 2/10D. Furthermore, it is not expected that residual contamination from test 2/10B would result in such high levels in two subsequent tests. These tests used the doped pellets instead of the dopant disks and only a single pellet was chemically analyzed to determine the amounts of dopant and these levels were assumed to be those present in all the other pellets. There was a very high level of uncertainty in the Ru amounts and it is possible that much higher levels of Ru were incorporated in these tests than has been assumed based on the analysis of the single pellet.

Test results for measured respirable fractions for ruthenium fission product dopants in Phase 2 tests were presented in [Brockmann et al., 2004]. These results, along with the results for test 2/10B, are shown in Figure 7.15 and in Table 7.15. Note that the most recent test has higher Ru RF values than the previous tests, and that some of the data for the previous tests had zeros for the Ru detected. This may be from the low levels of Ru present in the tests and the subsequent low levels in the samples, making detection difficult, giving us a fairly high uncertainty in Ru respirable fraction. The average measured respirable fraction for ruthenium was 3.7 ± 1.4 % for all particle collectors, or 5.0 ± 1.6 % from the Marple impactors only, both at the 99% confidence interval. Note that the actual Ru RF may be twice these values based on uncertainties in deposition losses in the sampling tube, to be quantified later.

The enrichment factor, EF, for Ru based on the tests with Marple impactor data (and ignoring the zero values) is 16 ± 5 with a 99% confidence interval.

Table 7.15 Phase 2 and 2+ Test Results for Ruthenium Dopant Respirable Fraction

	RuO_2 Disrupted		Ruthenium Respirable Fraction (%)						
Test	RuO_2 (mg)	Ru (mg)	Respicon	Respicon	Berner	Marple	Marple	Marple	Test Avg
2/4A	20.3	15.4	0.90%	0.80%	4.34%				2.01%
2/4B	22.5	17.1	0.29%	0.44%	2.17%				0.97%
2/5A	22	16.7	2.76%	2.66%					2.71%
2/5E	4.2	3.2				4.09%			4.09%
2/5G	3.5	2.7				3.07%			3.07%
2/6A	5.7	4.3				2.94%	2.94%	3.77%	3.22%
2/6B	6.7	5.1					5.84%	1.60%	3.72%
2/8C	6.4	4.9					4.19%		4.19%
2/8D	6.4	4.9							
2/10B	18.5	14.1				6.16%	9.62%	10.67%	8.81%
2/10C	0.47	0.36							
2/10D	0.47	0.36							
avg all			1.31%		3.26%			4.99%	3.65%

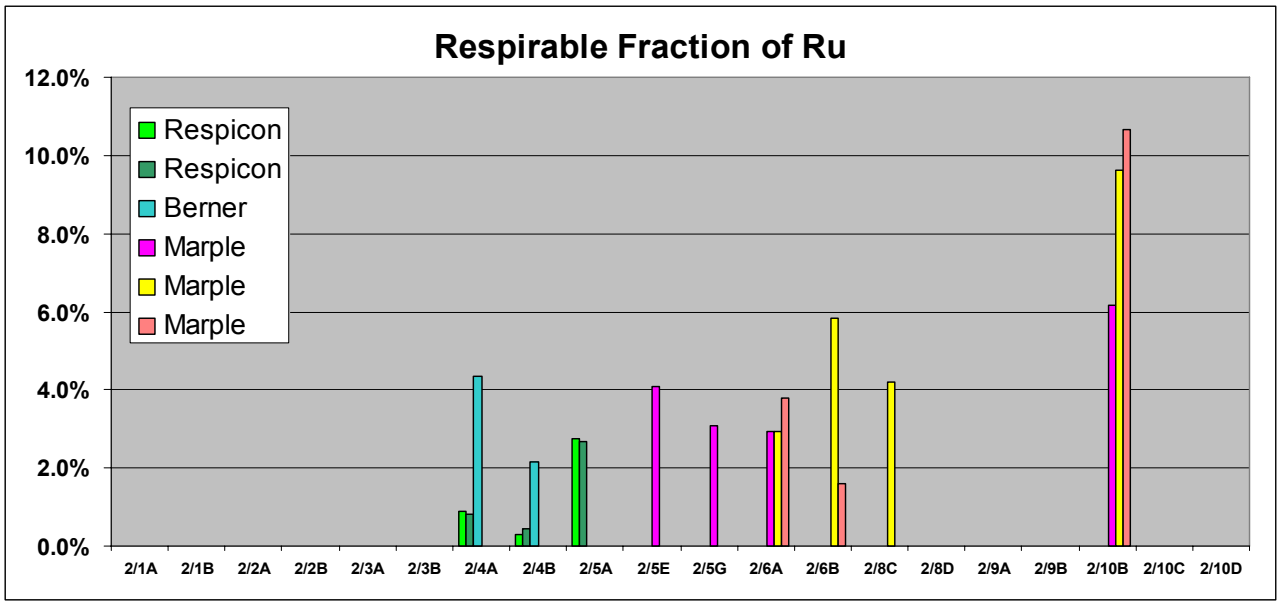


Figure 7.15 Phase 2 and 2+ Test Results for Ruthenium Dopant Respirable Fraction

Europium: Respirable fraction data for Eu are not calculated since Eu was detected at only about twice the background level to be expected from the collection substrate. Not enough information is available at present for an accurate estimate.

It is also difficult to interpret the measured particle data for fission product europium, included as a non-thermally volatile Eu_2O_3 dopant, again because of fiberglass media impurities. The Eu concentrations appear to be nearly constant and very high over the aerosol range from 30 to 100 µm AED, collected with the LPS apparatus, particularly with samples from test 2/10B L1, L2, and L3, plus samples from test 2/10C L2. It appears likely that the measured europium content results from impurity levels in the fiberglass filter media, obscuring the Eu levels particulated from the dopant material. However, Eu results from test 2/10C L5 and L6 plus test 2/10D L3, L5, and L6 are lower in concentration and indicate a concentration peak at ~30-48 µm. It seems likely that fiberglass strips from a different supplier may have been used

in the later LPS apparatus, without the high Eu impurity levels. The Eu fission product dopant concentrations obtained from the Marple impactor samples (M#) for all the 2/10B-2/10D tests do appear to have reasonable concentrations and some structure. For these tests, there appears to be a slight, broad Eu concentration peak over the 3.5-9.8 μm AED range.

Strontium: The most significant impact of these findings of impurities in the particle collection substrate materials is that strontium fission product data to be obtained from these tests have been obscured behind even larger amounts of Sr impurities. No interpretation of fission product strontium aerosol results can be provided, unfortunately. The strontium dopant, strontium oxide SrO, melts at 2693 K and boils at ~3270K; as such, it is unlikely to undergo phase change. The aerosol particles are expected to be that of the native (dopant) distribution of the SrO powder.

7.5 Aerosol Particle Electron Microscopy Results

Electron microscopy and energy dispersion x-ray spectroscopy (EDS) of respirable particulate material collected from stage 6 of the Marple impactor (~ 1.5 to 3.5 μm AED) from Phase 2 test 2/6A provides a good indicator of the aerosol composition and morphology. The aerosol particles collected are predominantly carbon soot with copper, from the HEDD detonation residue and jet, with a peak coincident with the mass distribution peak at 1 to 3 μm AED. This is very similar to the distribution of volatile fission product dopant cesium. These electron micrographs will provide a basis for further microscopic analysis and the morphology will assist in future modeling.

Electron microscopy micrographs show four types of particle morphology:
(1) Typical agglomerated particles that range from obvious chain aggregates to more compacted densely packed material. The major constituents are copper, iron, and aluminum, with some zirconium present. The agglomerations are likely soot with these materials condensed onto. Refer to Figure 7.16.

(2) Discrete particles and spheres, with some copper spheres that appear to have been molten. The major constituents are Cu and Ce, alone and in combination. Refer to Figure 7.17.

(3) Large particles, 10's of μm in size. These particles are monolithic in appearance, with cracks. They may have formed in situ or in the gas phase. They are possibly compact agglomerates with a very high void fraction, and are likely to be a form of soot. Refer to Figure 7.18.

(4) And, most interestingly, long, thin ribbons/wires or extrusions of copper, present as discrete particles and as constituents on agglomerates. There is obviously some material that never melted. Refer to Figure 7.19.

The small particle mode arising from soot formation provides multiple condensation sites for vapor and/or nucleation particles. Soot and Cu and Cs distributions are correlated. Copper is present everywhere and appears to enter the aerosol chamber as solid, liquid, and vapor. Cerium oxide is present as individual particles, with some that may have melted, refer to Figure 7.17. Cesium was not seen in EDS analysis. Iodine was seen in one micrograph, Figure 7.18. Other dopant materials have not been seen so far. More microscopy is needed.

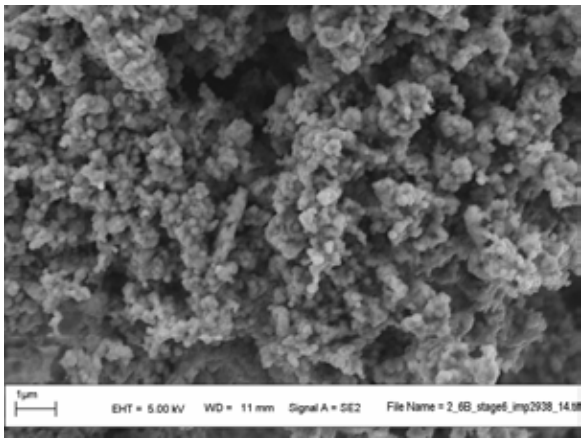


Figure 7.16 Electron Micrograph, Agglomerated Particles

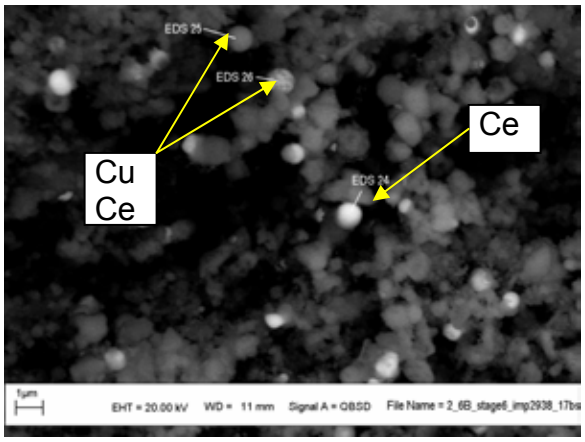


Figure 7.17 Electron Micrograph, Discrete Particles and Cu and Ce Spheres

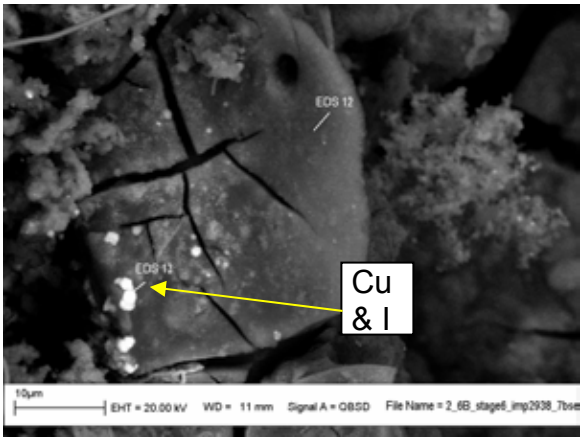


Figure 7.18 Electron Micrograph, Large Particles and Fractures

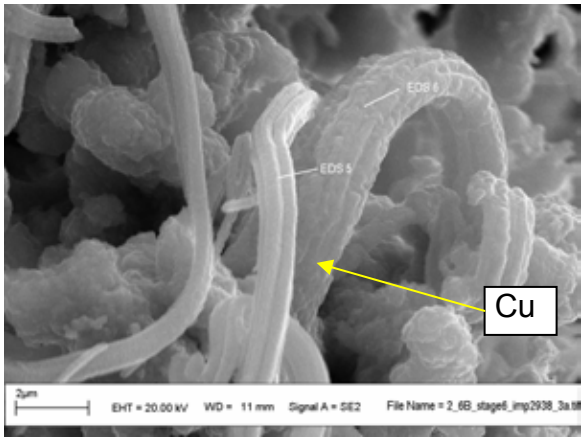


Figure 7.19 Electron Micrograph, Copper Extrusions

7.6 Phase 3 Test Aerosol Particle Data

The data and analyses presented from the first Phase 3 DUO_2 test, 3/2 (A) are presented in this section and will be compared, in a preliminary manner, to the Phase 2 and 2+ aerosol results.

7.6.1 Aerosol Results for Uranium Oxide

From observations of the Marple impactor uranium distributions in the respirable size range (as illustrated in multiple figures in Appendix A3), uranium particles appear to peak distinctly over the respirable range size of 1.6 to 3.5 µm AED, then increase again from 21 to 35 µm AED. The uranium particle distribution in the aerosol range from about 30 to 100 µm AED, collected with the LPS apparatus, is generally highest in the 30-48 µm cut (for tests 3/2 (A), then decreases, then increases somewhat in the 82 to 100 µm range (for both 3/2 (A) AND 3/5 (B)). NOTE: Starting with test 3/2 (A), an additional segment of LPS data is provided, segment #0, or L0. L0 is a Q-tip wipe of the inside of the LPS apparatus after the filter media had been removed, to obtain any particle that may have fallen off of the fiberglass media strip. The size range of collected particles is uncertain.

The ***respirable fraction*** **(RF)** produced when the CSC jet impacts a target rodlet is the fraction of a specific material (depleted uranium oxide, zirconium, fission product, etc.) *produced* (in the rod swept_volume, for particles of size 10 μm AED and smaller) divided by the total amount of those material particulated. The respirable fraction for DUO_2 is calculated from the aerosol measurements taken in the first two Phase 3 tests, 3/2 (A) and 3/5 (B), are reported in Table 7.16, and was illustrated in Figure 7.1. The later data from the two depleted uranium tests have an average RF for DU of 1.31 ± 0.41 % (with a 99% confidence interval). This preliminary DU RF value is very consistent with the earlier surrogate cerium oxide sample RF results from all gathered data, 1.34 ± 0.56 %, or of 0.61 ± 0.25% based on the Marple impactor data (with a 99% confidence interval); refer to Table 7.1.

No fission product dopants were incorporated into the test 3/2 (A) and 3/5 (B) rodlets; they were incorporated in test 3/1 (C), but results are not yet available. Minor levels of Cs, Ru, Sr, and Eu (in particular) were, however, measured, as listed in the data tables in the Appendix, and must be attributed to impurity concentrations from the fiberglass filter media used, as was the case for Phase 2+ tests. No other fission product interpretation is appropriate. Starting with the second Phase 3 DUO_2 test, the fiberglass filter media were replaced with high purity quartz fiber filer media (SiO_2 content) and in the third test, two impactors used Mylar and two used quartz fiber substrates.

Table 7.16 Phase 3 Test Results for Depleted Uranium Oxide Respirable Fraction

	DUO_2 Dispersed		**Depleted Uranium Oxide Respirable Fraction (RF %)**				
Test	**DUO_2** (mg)	**DU** (mg)	**Marple 1**	**Marple 2**	**Marple 3**	**Marple 4**	**Test Avg.**
3/2 A	**26357**	**29900**	**1.71%**	**0.93%**		**1.15%**	**1.26%**
3/5 B	**26357**	**29900**	**0.68%**	**1.28%**	**1.59%**	**1.81%**	**1.34%**
3/1 C							

8. NUCLEAR FACILITY ISSUES AND REQUIREMENTS

The combination of an explosive, high energy density device and highly radioactive Phase 4 spent fuel test rods gives rise to significant radiological safety testing concerns. These concerns have necessitated extensive facility environmental and safety assessment evaluations, contamination and radiation controls, plus remote handling and post-test, off-site disposition concerns. These same issues significantly increase testing expense and difficulty.

The initiation of radioactive Phase 4 spent fuel testing in the GIF, in Sandia Tech Area-V (TA-V), is still awaiting finalization of the GIF Documented Safety Analysis, DSA, a formal safety authorization approval process as well as approval for post-test storage of the experiment hardware. This is a joint SNL and DOE Sandia Site Office, SSO (NNSA), operation. Sandia's safety approval processes have been funded in part with prior NRC support.

8.1 GIF Documented Safety Analysis

The Phase 4 tests to be performed in the GIF use small test rodlet samples of highly radioactive spent reactor fuel. These tests are a vital part of the SFR determination and the driving force for the entire spent fuel sabotage / spent fuel ratio program. Phase 4 testing involves highly radioactive materials that pose not only a direct radiation threat to associated workers, but also an inhalation threat to the workers, co-located workers, and the public, if not confined. Contamination of the GIF facility is also a significant concern, which must be protected against. The conduct of these tests will require special remote handling equipment as well as validated processes to ensure safety to the worker, co-located workers, and the public, as well as to ensure minimal impact on the facility assets. Transportation and post-test disposition are significant issues both for the receipt of the spent fuel samples and post-test transportation and off-site storage disposition of the fuel and contaminated equipment. SNL requires that all of these issues be resolved prior to initiation of Phase 4 testing. The issue resolution and approval processes have, unfortunately, produced appreciable delays to the Phase 4 testing schedule during FY 2005.

The SNL GIF, Test Cell 3, has been previously operated as a clean facility for gamma irradiation testing only, with no radioactive contamination. The GIF is classified as a Hazard Category 3 nuclear facility with a DOE approved Documented Safety Analysis, DSA. However, the existing, previous safety basis documentation did not adequately address the use of explosives and fissile materials, specifically spent fuel, due to the lack of description and analysis in the original DSA. The primary issue involved is the use of explosives with fissile materials in the facility and their implications for personnel safety, potential for damage to assets, and unmitigated release to the public. Updated GIF DSA plus Technical Safety Requirements (TSR) documents are required and are being revised to explicitly accommodate the unique needs and requirements of the Phase 4 spent fuel tests, to assure alignment with current DOE documentation requirements and interpretations of those requirements.

Sandia TA-V activities for the past year have been focused on the process for obtaining authorization from DOE to perform explosive-aerosol testing in the GIF. Feedback received by Sandia from DOE SSO staff in 2004 indicated that the GIF Documented Safety Analysis approval would be received by late summer 2004. By November 2004, the GIF test schedule was projected to slip, conservatively by about 7 to 9 months, to start about June 2005, and finish in March 2006. These earlier schedule projections were also delayed and were attributed to DOE SSO deliberations with both the Defense Nuclear Facility Safety Board and SNL over

safety authorizations for all of Sandia nuclear facilities, including the GIF. As a result, the SSO review and approval process has taking appreciably longer than anticipated. The delays with the document approval are not necessarily specific to, nor caused by, the planned explosive-aerosol testing with spent fuel test rodlets.

Subsequent delays were based on the need to upgrade the GIF DSA review and approval process. Sandia is involved in a major upgrade of its safety-basis program, with the result that all the nuclear facility DSAs are being upgraded. Unfortunately, the GIF was assigned a lower priority, based on available resources, than the two nuclear reactor facilities at SNL, which subsequently have been formally approved. The formal GIF DSA safety basis approval to DOE SSO was revamped to include both a 50% review then a 100% review approval process. The 50% approval process was submitted to DOE in late 2005 and accepted, after several comment resolution iterations in early 2006. The 100% review cycle process is currently underway and includes: SNL Environmental Safety and Health – Safety Basis review; SNL Legal review; Radiation Control Safety Committee (RCSC) review; Nuclear Facility Safety Committee (NFSC) review; and then, DOE SSO review. Once the GIF DSA is approved by SSO, they will issue a Safety Evaluation Report (SER). Once the SER has been issued, following incorporation of any required conditions of approval, SNL will be authorized to perform the Phase 4 spent fuel testing.

Significant progress has been made on the GIF DSA under the new review and approval process. Based on the delays experienced to date due to the lengthy review and approval cycles, and current expectations, the safety basis approval process for the GIF, including the DOE SSO SER, should be concluded in the last quarter of 2006, it is tentatively scheduled by October 24, 2006. The GIF DSA approval is no longer considered a critical path schedule stumbling block, even if it potentially slips by several months. We anticipate, therefore, that it should be possible to set up and perform the last two of the non-radioactive Phase 2/Phase 3 cross-over tests (2/9D and 2/9E, as described in Section 3) in the GIF by the end of 2006 or shortly thereafter. Performance of all eight Phase 4 spent fuel tests in the GIF should commence during 2007.

In addition, the following SNL *internal* documents and procedures are required for the performance and support of Phase 4 spent fuel testing in FY 2007, and are in advanced stages of development, or completed and signed off:
(a) a Design Requirements Document for Spent Fuel Ratio Testing Campaign in the GIF;
(b) the Project Plan for the SNL Technical Area V, TA-V, GIF test campaign;
(c) the Project/Experiment Quality Plan, PEQP;
(d) a specific PHS/HA (project health and safety hazard analysis) evaluation,
(e) a test program schedule (on a sliding time schedule, awaiting the GIF DSA approval);
(f) a GIF Radiation Work Permit, RWP;
(g) an Acceptance Test Plan; and,
(h) a GIF experiment plan, etc.

Further details and status of these plans, procedures, and documents will be made available in the future. Other areas of work performed by SNL TA-V personnel in FY 2005 are the required test hardware design, procurement, and fabrication activities to support SFR Phase 4 testing in the GIF. Other items include the GIF pit liner and associated elevator, target transfer carrier for shipping spent fuel test rodlets from ANL to SNL within a GE-100 cask, and GIF manipulator activities. Future activities will be focused on hardware fabrication.

8.2 Phase 4 Post-Test Issues

Each of the Phase 4 test spent fuel chambers will be used *one time only*, temporarily stored at SNL in the GIF floor vault, with the explosively-disrupted, post-test spent fuel rodlet and residual particulates contained within, then shipped off-site to an approved, limited-term radioactive material (temporary) storage facility (tentatively at the Idaho National Laboratory) prior to final disposal, when a licensed facility (presumably Yucca Mountain repository) is available to accept these chambers

Sandia Radiation Sciences Center, 1300, staff and management (responsible for nuclear facilities in SNL Technical Area V, TA-V, and GIF operations) and the DOE Sandia Site Office have mandated that a spent fuel disposal pathway for these test materials must be specified and authorized before the spent fuel test rodlets can be received at, and tested at Sandia. This requirement also controls the schedule of fabrication finalizations at Argonne National Laboratory and Argonne's preparation of a formal transportation plan (from Argonne to SNL, in an approved GE-100 cask). This is a **critical path** requirement that mandates DOE RW support and authorizations for resolution. During FY 2005 and 2006, DOE RW entered into discussions with DOE EM (Environmental Management) and DOE-Idaho in order to get this task accomplished; these negotiations are still in process.

It is planned to transport each post-test Phase 4 chamber to the limited-term radioactive material (temporary) storage facility within an approved GE-2000 spent fuel transport cask. In order to use the GE-2000 cask, modifications to the cask Certificate of Compliance (CoC) must be made and then approved by the U.S. Nuclear Regulatory Commission (NRC). The CoC modification is required because criteria in the current CoC limit the spent fuel to be transported to a maximum burnup of 52 GWd/MTU; the peak burnup of the test rodlets originating from the H.B. Robinson reactor spent fuel are about 72 GWd/MTU.

During FY 2005, SNL has worked with GE Vallecitos to revise the Certificate of Compliance for the GE 2000 transport cask and then obtain NRC approval. GE will provide the necessary support to prepare and submit a license amendment to the NRC authorizing the use of the Model GE-2000 cask for transport of high burnup irradiated nuclear fuel sections for SNL needed purposes. This work is estimated to take about three months of work, once initiated. Sandia has submitted a purchase requisition to GE Vallecitos for performing this work, but it is not anticipated to be funded and approved until 2007. SNL has also discussed preliminary details of this planned work with NRC, for guidance.

8.3 Phase 4 Test Rodlet Pressurization Issues

The requirement to fabricate and use pressurized spent fuel test rodlets for the Phase 4 tests was previously requested by WGSTSC test partners, in order to demonstrate to critics that they would be typical of real spent fuel and were similar to large-scale tests done with pressurized surrogate fuel rods in tests performed in the early 1990s [Lange, et al., 1994]. Based on the experimental observations of short, surrogate test rodlet pressurization effects, or lack thereof -- as detailed in Section 7.1, the existing technical data and opinion do not support the absolute need for test rodlet pressurization for Phase 4 spent fuel test rodlets. Therefore, WGSTSC partners agreed to go forward without the pressurization requirement, recognizing that fine, aerosol particle blow-down release from the short test rodlets will not be significant compared to the data scatter of all previous experiments.

9. TEST PROGRAM SUMMARY

In this technical report, we document a thorough overview of the FY 2005 and 2006 progress, all data generated, and aerosol data interpretations for the ongoing surrogate and spent fuel sabotage – aerosol test program. This test program was designed to quantify and characterize aerosol particles ***produced*** in a credible sabotage event on a spent fuel transport or storage cask, has been performed primarily at SNL since 2002. There has been major design input, participation, and supplemental testing from other U.S., German, French, and British partners, as part of the collaborative, International WGSTSC; contributions from all test participants are incorporated into this report.

This current "simplified single short-rodlet" testing portion of the overall program is designed to provide reliable, quantified source-term input data including measurements of particle Respirable Fractions, Enrichment Factors -- the enhanced sorption of volatile fission products onto the respirable particles, and the Spent Fuel Ratio. These results are used as input to, and support for parallel follow-on modeling efforts of near-field aerosol dispersion, computational fluid dynamics, and radiological consequence assessments.

During the preceding FY 2004, we essentially completed Phase 2 of this test program with surrogate cerium oxide target pellet materials, tests 2/5A through 2/8D, having performed a total of 24 explosive-aerosol tests. We also performed two Phase 2 / Phase 3 cross-over tests in late FY 2004, 2/9A and 9B, and 2/9C during November 2004, using non-radioactive CeO_2 test rodlets and the new, optimized, Phase 3 aerosol-explosive vertical test chamber, to be used for all following DUO_2 Phase 3 tests. A detailed technical report of the overall program, data, and analyses to date was documented in SAND2005-4446, *Spent Fuel Sabotage Aerosol Ratio Program: FY 2004 Test and Data Summary* [Molecke et al., 2005a]. We also formally documented the results achieved in the earlier Phase 1 of the test program, in SAND2005-5873, *Surrogate/Spent Fuel Sabotage Aerosol Ratio Testing: Phase 1 Summary and Results* [Molecke et al., 2005b].

The predominant aerosol-explosive testing performed at SNL during FY 2005 and the first-half of FY 2006 consisted of the conduct of six new Phase 2+ tests, essentially completing surrogate, non-radioactive testing, plus the conduct of the first three Phase 3 tests using slightly radioactive, non-irradiated depleted uranium oxide pellet rodlets. These DUO_2 test rodlets were provided to SNL by our French test partner, IRSN. During this same time period, we have also analyzed and interpreted a large body of recently obtained, chemically analyzed, aerosol particle data.

The Phase 2+ tests were specifically added to the overall program to further evaluate the release and sorption enhancement of cesium, ruthenium, strontium, and europium fission product dopants as a function of several variables, as recommended by International WGSTSC test partners at the 8th Technical Meeting of the WGSTSC, in Albuquerque, during November 2004. Two final Phase 2+ tests will be cooperatively performed in Germany in June 2006, by personnel at the Fraunhofer Institut (both the Institut für Toxikologie und Experimentelle Medizin, ITEM, and the Ernst-Mach-Institut, EMI, in Holzen, Germany). These two tests are essentially identical to cerium oxide tests 2/10C and 2/10D conducted at SNL, except that the aerosol particle collection system will use the Fraunhofer vertical elutriator particle sampling system. Additional surrogate, fission product-doped HAW/HLW glass targets may also be added.

The Phase 3 DUO_2 tests are required to determine the spent fuel ratio (SFR), along with results from the to-be-performed Phase 4 tests with actual spent fuel rodlets. The Phase 3 DUO_2 tests were originally scheduled to be performed in the SNL GIF radiation facility [Molecke et al., 2004a, 2005a] but were moved to the SNL Explosive Components Facility (ECF) during 2005, with a significantly enhanced, positive impact on test schedules. The ECF building had not been used previously for radioactive testing of this type or scope, so this move required: approved documentation of a NEPA amendment for the ECF; a Preliminary Hazard Screening/ Hazard Assessment review and approval; and, the need to include appropriate secondary containment of the test chamber within the ECF explosive blast chamber, to address potential release of particulate radioactive materials. These needs were satisfied and three DUO_2 explosive-aerosol tests were successfully completed, to date. Negligible amounts of particulate contamination (at or below measurable levels) were released from the leak-tight test chamber during conduct and post-test sample retrieval and during component decontamination procedures (prior to the subsequent test).

Final required safety basis authorization to use the SNL GIF facility for these tests is progressing forward. The SNL GIF Documented Safety Analysis 100% review process document is scheduled to be approved by DOE Sandia Site Office, with the issuance of a final GIF Safety Evaluation Report (SER) before the end of 2006. This is a major accomplishment allowing the anticipated start of Phase 4 spent fuel testing in 2007.

In addition, plans initiated in 2006 by GRS and Fraunhofer Institut (ITEM and EMI) are in transition to perform joint-WGSTSC partner ("common project") large-scale tests in Germany with multiple bundles of surrogate material rods in an actual cask-volume enclosure, with representative cask wall materials and a larger HEDD device. These planned large-scale tests are to measure the relative amount of aerosols ***released*** (internal distribution and amounts blown out) through the sabotage-produced hole in the "cask." Several parallel modeling studies have been initiated by WGSTSC partners to help tie together results and interpretations from both the "simplified single test rodlet" (as described in this report) and planned large-scale WGSTSC test programs to both previous [Molecke et al., 2005a; Sandoval et al., 1983; Lange et al., 1994; Luna et al., 1999] and future analyses.

9.1 Overview of Current Data and Results

The average, measured respirable fraction (RF) for surrogate, Phase 2 and Phase 2+ CeO_2, is 0.61 ± 0.25 %, based on the most recent Marple impactor data, or 1.34 ± 0.56 %, based on older and new data, both with a 99% confidence interval. Similarly, the preliminary measured RF for Phase 3 DUO_2 is 1.31 ± 0.41 %, based on results from the first two tests only. The CeO_2 and DUO_2 measured RF values are quite similar and consistent, as expected.

There could be, however, appreciable particle deposition loss in the aerosol sampling hardware lines from thermophoretic or diffusiophoretic deposition effects in these tests, with a measured high internal temperature, onto initially room-temperature test hardware. The extent of these deposition losses is still being quantified and is anticipated to be complete by early FY 2007. Sampling uncertainties will be addressed through aerosol laboratory testing, characterization, calibration and modeling; the Marple Impactor and Large Particle Separator will be calibrated and inlet line sampling efficiency will be tested and calibrated. As such, all aerosol results reported in this document must be qualified as being "preliminary" in nature. It is tentatively estimated that the particle deposition effects might double the measured respirable fractions. Even so, these surrogate CeO_2 and DUO_2 RF values are appreciably below, but not

inconsistent with, the 5% RF value for spent fuel used in an earlier Yucca Mountain Program analysis [Luna et al., 1999]. The current RF results suggest that the estimated respirable particle release predicted in that earlier analysis is likely to be somewhat conservative, i.e., the radiological consequences of a sabotage event on a spent fuel transport cask may not be as significant.

Similarly, the observed cesium fission product dopant respirable fraction was 30 +/- 7.6 % of dispersed mass based on Marple impactor data only, or 28 +/- 6% based on all data collected, both reported at the 99% confidence interval. The higher observed values for cesium RF (compared to the cerium oxide pellet material) indicate that the cesium is enhanced in the smaller-sized particle range, 0 – 3.5 μm AED. The measured/calculated, integrated respirable cesium fission product *enrichment factor* (EF) is 64 +/- 34 of dispersed (particulated) mass based on all data, or 79 +/- 45 based on Marple impactor data only. The observed cesium EF *range* of about 5 to 160 is a clear indication that a significant amount of the cesium fission product species is both mechanically particulated *and* thermally volatilized. The CsI used as the dopant chemical undergoes a phase change during the explosive-aerosol process, then preferentially sorbs onto the other respirable size particles produced: carbon soot-explosive residue, copper particles from the HEDD jet, and particles of surrogate fuel pellet.

There were some observed differences in the measured cesium EF results between the physical forms of the dopant material used, whether located in external, non-homogeneous solid chemical wells in the pellets, or adjacent resin-based disks, or in a more nearly homogeneous distribution of these dopants within the CeO_2 pellets -- similar to the situation expected for fission products in actual spent fuel, irradiated UO_2 pellets. Recent cesium EF data from Phase 2+ tests with doped cerium oxide pellets and doped German HAW/HLW glass surrogate indicate lower EF values for Cs in the partially vented chamber with an external detonation of the HEDD compared to the closed test chamber with internal detonation (Phase 2 and 3 tests), with more carbon soot present and with higher chamber gas temperatures. These preliminary cesium EF findings will be investigated further after results from the final two Phase 2+ tests performed in Germany are available. Further analyses are necessary to understand the large scatter of observed cesium EF and to derive enrichment factors which are adequate for the assessment of real, i.e., large-scale HEDD sabotage scenarios.

Ruthenium fission product dopant concentration levels in the Phase 2+ tests were very low and uncertain, but data was obtained giving Ru RF values of 3.7 +/- 1.4 % for all data and 5.0 +/- 1.6 % based on the Marple data (99% confidence interval). The measured Ru enrichment factor was 16 +/- 5. Europium was not detected at high enough levels to determine RF values. Strontium RF data was obscured due to unanticipated Sr contamination in the fiberglass substrates used in the Marple impactors; this substrate contamination issue was resolved by the end of 2005.

9.2 Programmatic Summary

During FY 2005 and through May 2006, SNL, Argonne National Laboratory, DOE, NRC, GRS, Fraunhofer, and IRSN program participants participated in four technical meetings of the International Working Group for Sabotage Concerns of Transport and Storage Casks. The 8th Technical Meeting of the WGSTSC was held in Albuquerque, NM, and hosted by Sandia National Laboratories, in November 2004, the 9th Technical Meeting was in Cadarache, France, in May 2005, hosted by IRSN, the 10th Technical Meeting was again held in Albu-

querque, NM, in November 2005, and the 11th Technical Meeting was in Garching, Germany, in May 2006, hosted by GRS.

Ten Sandia Technical Reports, journal, and conference presentations were completed during FY 2005 and 2006 to date:

1. Molecke et al, SAND2004-5740C, *Spent Fuel Sabotage Aerosol Ratio Test Program, Status Update November 2004,* presented at the 8th Technical Meeting of the WGSTSC, November 2004.
2. Brockmann et al, SAND2004-6008C, *Aerosol Sampling and Results,* presented at the 8th Technical Meeting of the WGSTSC, November 2004.
3. Luna et al, SAND2004-6203C, *Respirable Aerosols Resulting from HEDD Interaction with Surrogate Fuel Pellets*,. Presented at WM '05 Conference, Tucson, AZ. February 2005.
4. Molecke et al, SAND2005-2940C, *Spent Fuel Sabotage Aerosol Ratio Program: Status, May 2005,* presented at the 9th Technical Meeting of the WGSTSC, May 19-20, 2005, Cadarache, France.
5. Molecke et al, SAND2005-4071C, *Spent Fuel Sabotage Test Program and Surrogate Aerosol Particle Analyses Update,* presented at INMM 46th Annual Meeting, Institute of Nuclear Materials Management, July 10-14, 2005, Phoenix, AZ.
6. Molecke et al, SAND2005-4446, *Spent Fuel Sabotage Aerosol Ratio Program: FY 2004 Test and Data Summary*, July 2005.
7. Molecke et al, SAND2005-5873, *Surrogate/Spent Fuel Sabotage Aerosol Ratio Testing: Phase 1 Summary and Results***,** September, 2005.
8. Molecke et al., SAND2006-2679C, *Spent Fuel Sabotage Aerosol Test Program: Progress, November 2005*. November 2005.
9. Brockmann et al., SAND2006-xxxxC, *Aerosol Sampling and Analysis*. November 2005.
10. Molecke et al., SAND2006-2679C, *Spent Fuel Sabotage Aerosol Test Program: Update, May 2006.* May 2006.

Several meetings were also conducted between SNL Dept. 6141 (Materials Transportation Testing and Analysis) plus Dept. 10264 (Shipping and Transportation) staff and management, plus DOE Sandia Site Office staff to initiate required planning for posttest, off-site shipments of spent fuel sabotage test chambers from Sandia. Focus was on relevant post-test container transport requirements, per the information needs of the Western Governors Association.

In conclusion, there are significant benefits and regulatory needs for the successful completion of this WGSTSC program for all participants involved. This program supports the U.S. DOE on international sabotage and security evaluations, and partner German, French, and British organizations to provide a measured basis for evaluating appropriate levels of physical protection, safeguards requirements, and preventative strategies for nuclear materials in use, transport, and storage (including the Yucca Mountain repository transportation program). The experimental program provides reliable source-term data and analyses for a defensible validation of U.S. NRC vulnerability studies associated with the transport and storage of spent nuclear fuels (10 CFR Parts 71, 72, and 73), and follow-on computer modeling of aerosol dispersal hazards and radiological consequence assessments relevant to a credible sabotage attack. The measurement of the Spent Fuel Ratio allows scaling between simplified single rodlet results (as reported herein) and larger, cask-scale environments (with either surrogate or actual spent fuel materials). The continuing, successful conduct of this International WGSTSC cooperative program helps leverage test work and analyses across international organizations, and provides significant technical and policy benefits for all participants.

APPENDIX A, Aerosol and Particle Analysis Results

All available aerosol particle results from Phase 2 tests performed during FY 2005 and subsequent chemical analyses are included in this Appendix, including: ICP-MS analyses from particle impactor stages of Marple and Large Particle Separator aerosol apparatus used; similar data from collected and sieved impact debris particulates; plus, gravimetric analyses from aerosol filtrate media, brushings from within the internal aerosol sampling tubes, and wipes from internal test chamber surfaces.

Results from Phase 2/Phase 3 cross-over tests 2/9A and 2/9B, performed in FY 2004 are also included because all of these chemical analyses were not available to include in [Molecke et al., 2005a]. Aerosol particle impactor and impact debris data plus associated elemental analyses collected for earlier FY 2003 Phase 2 tests 2/1A through 2/4B have been compiled and fully documented in Appendix A of [Molecke et al., 2004a]. Similar results and analyses for FY 2004 Phase 2 tests 2/5A through 2/8D were fully documented in Appendix A of [Molecke et al., 2005a].

A.2 Aerosol Particle Measurements, Phase 2 and 2+ Tests

A.2.9A Test 2/9A Analyses and Results

Graphs of gravimetric particle size distributions from the four 2/9A Marple impactors, plus the mass concentrations, were presented in Figures A1.9.1 – A1.9.5 in [Molecke et al., 2005a].

Three separate impact particle debris samples were collected by a HEPA vacuum system from various sample points within the top aerosol chamber. The exact sample points in the chamber were specified only as "Bottom #1, Bottom #2, and "Sides/Top." Each set of particle debris was sieved using a set of 48mm-diameter sieves; 1000 µm, 500 µm, 250 µm, and 125 µm (geometric) with a final catch pan. The 'fines' were then sieved further with disposable mesh sieves at 100 µm, 74 µm, 37 µm, and 25 µm to further differentiate the debris. These debris sample weights are summarized in Table A2.9A.1.

Table A2.9A.1 Test 2/9A, Weight Distribution of Impact Debris

Sieve Fraction (geometric)	Bottom #1		Bottom #2		Sides/Top	
	Weight, g	%	Weight, g	%	Weight, g	%
1000 µm	2.3262	28.49	7.0265	61.36	0.734	22.02
500 µm	1.1633	14.25	0.9465	8.27	0.3933	11.80
250 µm	1.9648	24.06	1.2089	10.56	0.6887	20.66
125 µm	1.5881	19.45	1.1293	9.86	0.6873	20.62
100 µm	0.3701	4.53	0.2882	2.52	0.1813	5.44
74 µm	0.4341	5.32	0.4274	3.73	0.2888	8.66
37 µm	0.277	3.39	0.369	3.22	0.3155	9.46
25 µm	0.0159	0.19	0.0301	0.26	0.0182	0.55
<25 µm	0.0254	0.31	0.0245	0.21	0.0265	0.79
Total	**8.1649**	**100.00**	**11.4504**	**100.00**	**3.3336**	**100.00**

Microphotographs of the sieved debris material from four size fractions (1000 µm, 500 µm, 37 µm, and <25 µm) from the Bottom #1 sample are shown in Figures A2.9A.1-A2.9A.4, for illustration. From Figure A2.9A.1, 1000 µm, it appears that most large debris is Zircaloy tube fragments,

with some copper coating. From Figure A2.9A.2, 500 µm, the fragments appear to be copper-coated cerium oxide or copper from the CSC cone. The 37 µm particles in Figure A2.9A.3 appear to be mostly cerium oxide coated with copper and soot; the <25 µm particles in Figure A2.9A.4 appear similar.

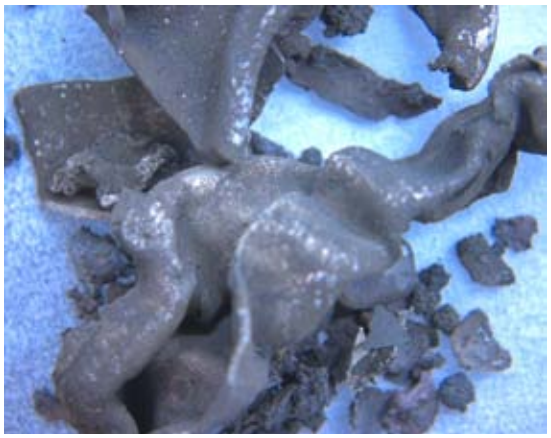


Figure A2.9A.1 Test 2/9A Bottom#1 debris 1000 µm fraction

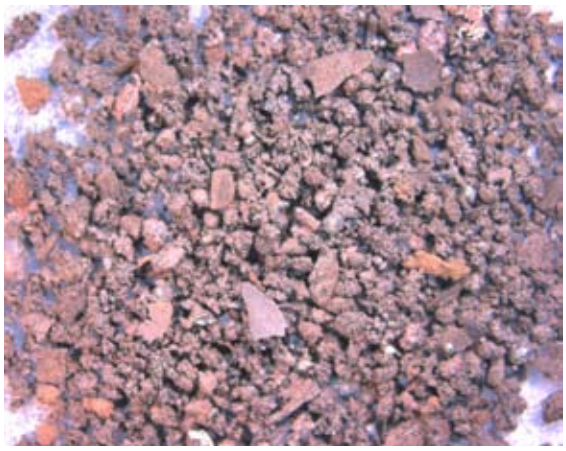


Figure A2.9A.2 Test 2/9A Bottom#1 debris 500 µm fraction

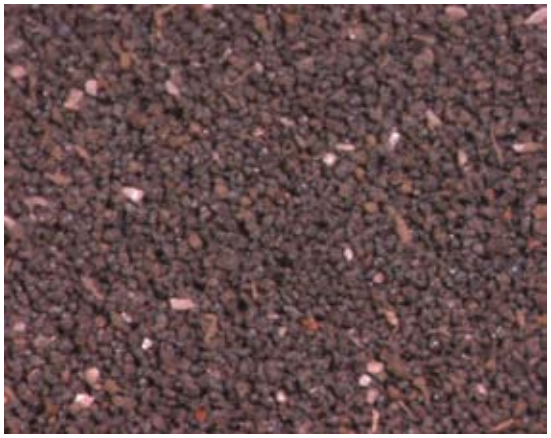


Figure A2.9A.3 Test 2/9A Bottom#1 debris 37 µm fraction

Figure A2.9A.4 Test 2/9A Bottom#1 debris <25 µm fraction

Elemental Analysis of Impact Debris: The sieved fractions of interest were homogenized by grinding with a mortar and pestle. An approximately 0.05 gram portion of the ground fraction was digested in a Teflon beaker using 10 mL of concentrated nitric acid (HNO3) with refluxing for 30 minutes. After cooling, 4 mL of concentrated hydrofluoric acid (HF) was added, and the mixture heated for an additional 30 minutes. After cooling a second time, and additional 5.0 mL of 30% hydrogen peroxide was added, and this mixture was heated to reduce the solution volume to <1 mL. The reduced preparation was cooled, and 10 mL of conc. HNO3 was added. This sample was heated for 30 minutes, cooled, and then 5 mL of 30% hydrogen peroxide (H2O2) was added and allowed to react. This mixture was heated for 30 minutes, and then cooled. This digestate was then diluted to 100 grams with DI water and analyzed by inductively coupled plasma/mass spectrometry (ICP/MS).

The impact debris elemental analysis for the Bottom #1 sample is listed in Table A2.9A.2. The weight % distribution of major metals in this impact debris is shown in Figure A2.9A.5. The elemental results for the Bottom #2 and Sides/Top samples are essentially identical.

Table A2.9A.2 Test 2/9A Elemental Analysis Wt% of Bottom #1 Sieved Impact Debris

Test 2/9A Sieve Fraction	125 µm	100 µm	74 µm	37 µm	25 µm	<25 µm
Cerium	44.480	45.400	45.620	44.590	41.600	38.570
Iron	16.910	16.220	15.790	16.240	16.470	16.510
Copper	7.255	7.184	7.496	7.618	7.502	7.296
Zirconium	2.914	2.867	3.018	3.169	3.295	3.330
Aluminum	1.451	1.941	2.138	2.169	3.000	4.162
Manganese	0.262	0.222	0.193	0.210	0.214	0.220
Tin	0.046	0.053	0.057	0.067	0.085	0.106
Chromium	0.098	0.066	0.065	0.064	0.089	0.095
Magnesium	0.023	0.026	0.029	0.032	0.054	0.072
Boron	<0.001	<0.001	<0.001	<0.001	0.002	0.003
Lithium	0.040	0.032	0.033	0.031	0.046	0.048
Nickel	0.065	0.042	0.038	0.034	0.040	0.050
Titanium	0.004	0.003	0.003	0.003	0.004	0.004
Molybdenum	0.016	0.020	0.023	0.027	0.038	0.058
Lead	<0.001	<0.001	0.001	0.001	0.001	0.002
Barium	0.262	0.222	0.193	0.210	0.214	0.220
Total *	**73.573**	**74.084**	**74.513**	**74.264**	**72.449**	**70.534**

* includes "minor" lanthanides: Lanthanum, Praeseodymium, Neodymium, Terbium, at 0.001-0.006

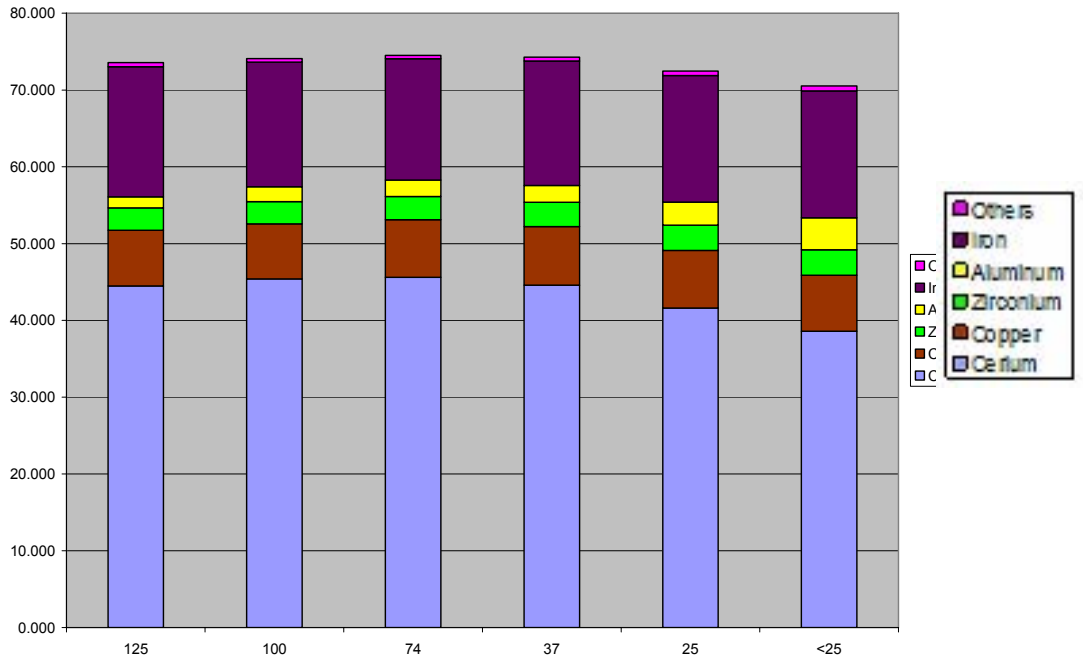


Figure A2.9A.5 Test 2/9A Weight % Distribution of Major Metals, Bottom #1 Impact Debris

Marple Particle Element Analyses: Particulates were sampled using a four independent Large Particle Separator and Marple impactor systems. Chemical analyses were made for threee of the four sampling sytems. The sampling sytem with Marple #3 had a missing flow critical orifice; as such, no data are reported. For test 2/9A, the entire Large Particle Sampler fiberglass substrate, with particles nominally from 30 to 100 μm AED in size, was treated as a "pre-filter" and added to Marple stage 0, nominal cutoff of 35 μm, for elemental analyses by ICP-MS. All Marple #1 elemental analyses are listed in Tables A2.9A.3 to A2.9A.5 and are plotted in Figure A2.9A.6. Similarly, all Marple #2 elemental analyses are listed in Tables A2.9A.6 to A2.9A.8 and are plotted in Figure A2.9A.7, and all Marple #4 elemental analyses are listed in Tables A2.9A.8 to A2.9A.108 and are plotted in Figure A2.9A.8.

NOTE: No fission product dopant materials were used in test 2/9A and no analysis results for fission product elements are reported in the analyses above. However, strontium was observed in almost all of the Marple samples, in quantities as "high" as 0.0002 to 0.0011 mg per sample. This was finally tracked to impurity levels in the fiberglass substrate used, with strontium concentrations as high as 173 ppm. The fiberglass substrate was digested in HNO_3, HF, and water, then analyzed by ICP-MS. The major components of the fiberglass used were silicon, sodium, potassium, and calcium. Other elements present as impurities and quantified were, approximately: Ba = 41,000 ppm, Zn = 32,000 ppm, Al = 30,000 ppm, B = 29,000 ppm, Mg = 1300 ppm, Fe = 400 ppm, Zr = 200 ppm, **Sr = 155 ppm**, Mn = 12 ppm, and Pb = 10 ppm. No other elements greater than 10 ppm were found.

Table A2.9A.3 Test 2/9A Marple #1 Elemental Analyses, Stages 0-3

2/9A	STAGE 0			STAGE 1			STAGE 2			STAGE 3		
#2935	Particle size 35 μm			Particle size 21.3 μm			Particle size 14.8 μm			Particle size 9.8 μm		
	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading
Ce	0.0251	17.0	0.9	0.0204	6.5	3.4	0.0113	15.6	28.3	0.0158	5.9	1.4
Cu	0.0358	24.2	1.3	0.0466	14.9	7.8	0.0150	20.7	37.5	0.0109	4.1	1.0
Zr	0.0056	3.8	0.2	0.0077	2.5	1.3	0.0017	2.3	4.3	0.0036	1.3	0.3
Fe	0.0774	52.4	2.7	0.0925	29.5	15.4	0.0416	57.3	104.0	0.0355	13.2	3.2
Al	*0.0000*	*0.0*	*0.0*	0.1398	44.6	23.3	*0.0000*	*0.0*	*0.0*	0.1976	73.7	18.0
Mg	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	0.0011	0.4	0.1
Cr	0.0008	0.5	0.0	0.0012	0.4	0.2	0.0005	0.7	1.3	0.0006	0.2	0.1
Ni	0.0005	0.3	0.0	0.0007	0.2	0.1	0.0002	0.3	0.5	0.0002	0.1	0.0
Mn	0.0010	0.7	0.0	0.0014	0.4	0.2	0.0004	0.6	1.0	0.0004	0.1	0.0
Sn	*0.0000*	*0.0*	*0.0*	0.0004	0.1	0.1	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*
Mo	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*
Ti	0.0005	0.3	0.0	0.0011	0.4	0.2	0.0008	1.1	2.0	0.0011	0.4	0.1
Li	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*
Sb	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*
Pb	0.0010	0.7	0.0	0.0013	0.4	0.2	0.0003	0.4	0.8	0.0003	0.1	0.0
mg, Metals Found	0.1477	100.0	5.2	0.3135	100.0	52.3	0.0726	100.0	181.5	0.2680	100.0	24.4
mg, Filter Loading	2.8300			0.6000			0.0400			1.1000		

Table A2.9A.4 Test 2/9A, Marple #1 Elemental Analyses, Stages 4-7

2/9A	STAGE 4			STAGE 5			STAGE 6			STAGE 7		
#2935	Particle size 6.0 µm			Particle size 3.5 µm			Particle size 1.55 µm			Particle size 0.93 µm		
	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading
Ce	0.0187	7.5	17.0	0.0281	11.9	4.7	0.0354	7.1	2.3	0.0059	6.2	2.7
Cu	0.0138	5.5	12.5	0.0675	28.5	11.3	0.1707	34.2	11.2	0.0316	33.0	14.4
Zr	0.0051	2.0	4.6	0.0126	5.3	2.1	0.0252	5.0	1.7	0.0038	4.0	1.7
Fe	0.0412	16.5	37.5	0.1210	51.1	20.2	0.2476	49.5	16.3	0.0511	53.3	23.2
Al	0.1681	67.2	152.8	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*
Mg	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*
Cr	0.0006	0.2	0.5	0.0013	0.5	0.2	0.0030	0.6	0.2	0.0007	0.7	0.3
Ni	0.0002	0.1	0.2	0.0009	0.4	0.2	0.0021	0.4	0.1	0.0004	0.4	0.2
Mn	0.0005	0.2	0.5	0.0018	0.8	0.3	0.0044	0.9	0.3	0.0008	0.8	0.4
Sn	*0.0000*	*0.0*	*0.0*	0.0008	0.3	0.1	0.0046	0.9	0.3	*0.0000*	*0.0*	*0.0*
Mo	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	0.0004	0.1	0.0	*0.0000*	*0.0*	*0.0*
Ti	0.0009	0.4	0.8	0.0007	0.3	0.1	0.0009	0.2	0.1	0.0007	0.7	0.3
Li	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*
Sb	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*
Pb	0.0002	0.1	0.2	0.0019	0.8	0.3	0.0054	1.1	0.4	0.0008	0.8	0.4
mg, Metals Found	0.2500	100.0	227.3	0.2366	100.0	39.4	0.4998	100.0	32.9	0.0958	100.0	43.5
mg, Filter Loading	0.1100			0.6000			1.5200			0.2200		

Table A2.9A.5 Test 2/9A Marple #1 Elemental Analyses, Stages 8-9

2/9A	STAGE 8			STAGE 9								
#2935	Particle size 0.52 µm			Particle size final, 0.25 µm								
	mg	% detected	% loading	mg	% detected	% loading						
Ce	0.0050	6.9	3.8	*0.0000*	*0.0*	*0.0*						
Cu	0.0235	32.5	18.1	0.0015	26.3	2.1						
Zr	0.0055	7.6	4.2	*0.0000*	*0.0*	*0.0*						
Fe	0.0354	49.0	27.2	0.0033	57.9	4.7						
Al	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*						
Mg	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*						
Cr	0.0006	0.8	0.5	*0.0000*	*0.0*	*0.0*						
Ni	0.0002	0.3	0.2	*0.0000*	*0.0*	*0.0*						
Mn	0.0005	0.7	0.4	*0.0000*	*0.0*	*0.0*						
Sn	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*						
Mo	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*						
Ti	0.0008	1.1	0.6	0.0001	1.8	0.1						
Li	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*						
Sb	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*						
Pb	0.0004	0.6	0.3	0.0001	1.8	0.1						
mg, Metals Found	0.0723	100.0	55.6	0.0057	100.0	8.1						
mg, Filter Loading	0.1300			0.0700								

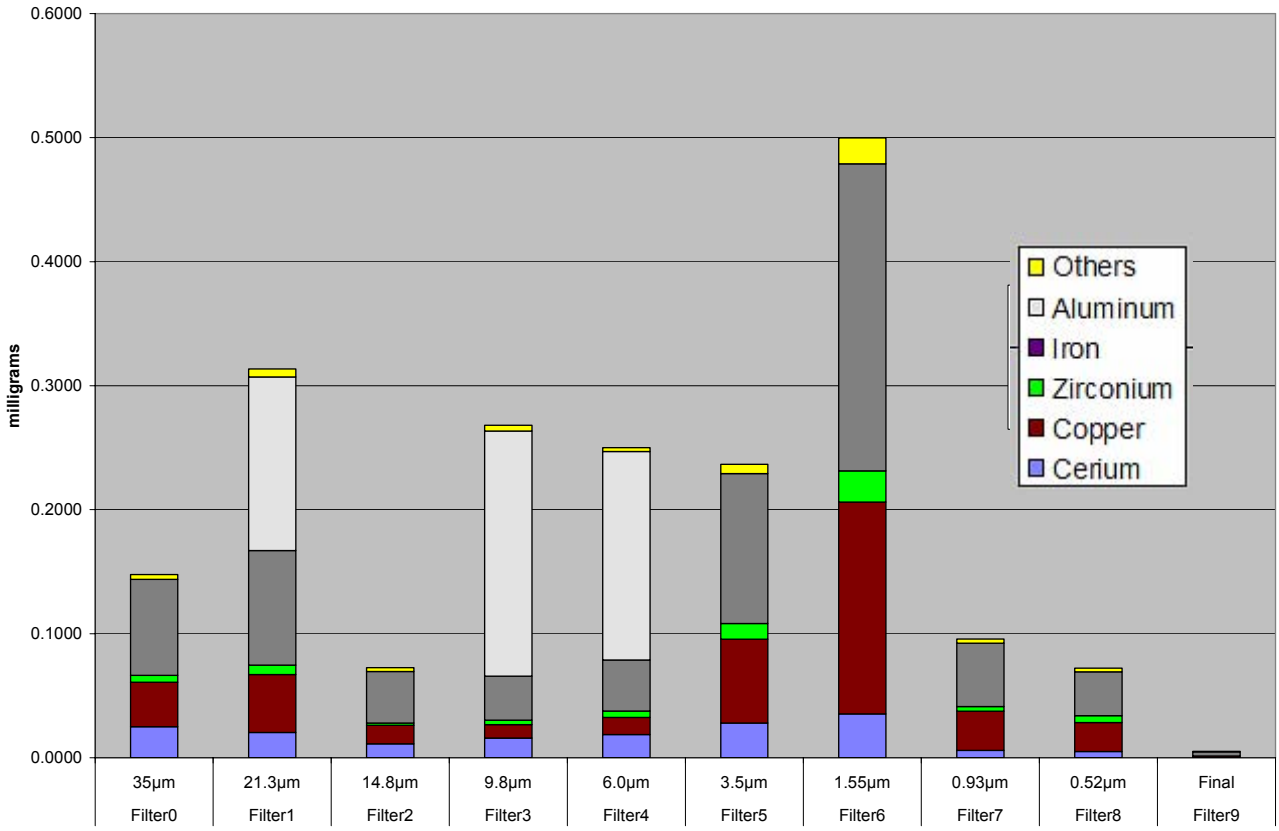


Figure A2.9A.6 Test 2/9A Marple #1 Metals Analysis Distribution, mg

Table A2.9A.6 Test 2/9A Marple #2 Elemental Analyses, Stages 0-3

2/9A	STAGE 0			STAGE 1			STAGE 2			STAGE 3		
#2937	Particle size 35 µm			Particle size 21.3 µm			Particle size 14.8 µm			Particle size 9.8 µm		
	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading
Ce	*0.0000*	*0.0*	*0.0*	0.0167	13.9	5.6	0.0156	22.1	11.1	0.0184	20.0	9.2
Cu	*0.0000*	*0.0*	*0.0*	0.0288	23.9	9.6	0.0148	21.0	10.6	0.0185	20.1	9.3
Zr	*0.0000*	*0.0*	*0.0*	0.0048	4.0	1.6	0.0022	3.1	1.6	0.0065	7.1	3.3
Fe	0.0002	40.0	40.0	0.0659	54.7	22.0	0.0352	49.9	25.1	0.0462	50.2	23.1
Al	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*
Mg	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*
Cr	*0.0000*	*0.0*	*0.0*	0.0009	0.7	0.3	0.0006	0.8	0.4	0.0006	0.7	0.3
Ni	*0.0000*	*0.0*	*0.0*	0.0005	0.4	0.2	0.0003	0.4	0.2	0.0003	0.3	0.2
Mn	*0.0000*	*0.0*	*0.0*	0.0009	0.7	0.3	0.0004	0.6	0.3	0.0006	0.7	0.3
Sn	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*
Mo	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*
Ti	0.0003	60.0	60.0	0.0008	0.7	0.3	0.0007	1.0	0.5	0.0007	0.8	0.4
Li	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*
Sb	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*
Pb	*0.0000*	*0.0*	*0.0*	0.0009	0.7	0.3	0.0003	0.4	0.2	0.0003	0.3	0.2
mg, Metals Found	0.0005	100.0	100.0	0.1204	100.0	40.1	0.0706	100.0	50.4	0.0921	100.0	46.1
mg, Filter Loading	0.0005			0.3000			0.1400			0.2000		

Table A2.9A.7 Test 2/9A Marple #2 Elemental Analyses, Stages 4-7

2/9A	STAGE 4			STAGE 5			STAGE 6			STAGE 7		
#2937	Particle size 6.0 µm			Particle size 3.5 µm			Particle size 1.55 µm			Particle size 0.93 µm		
	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading
Ce	0.0076	9.0	3.6	0.0175	4.0	1.8	0.0170	1.9	0.8	0.0073	5.9	2.9
Cu	0.0196	23.1	9.3	0.1272	29.0	12.7	0.2546	28.8	12.0	0.0419	34.1	16.8
Zr	0.0063	7.4	3.0	0.0210	4.8	2.1	0.0350	4.0	1.6	0.0054	4.4	2.2
Fe	0.0482	56.8	23.0	0.2558	58.4	25.6	0.4024	45.5	18.9	0.0631	51.3	25.2
Al	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	0.1439	16.3	6.8	*0.0000*	*0.0*	*0.0*
Mg	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*
Cr	0.0006	0.7	0.3	0.0027	0.6	0.3	0.0044	0.5	0.2	0.0009	0.7	0.4
Ni	0.0003	0.4	0.1	0.0018	0.4	0.2	0.0032	0.4	0.2	0.0005	0.4	0.2
Mn	0.0006	0.7	0.3	0.0037	0.8	0.4	0.0068	0.8	0.3	0.0010	0.8	0.4
Sn	*0.0000*	*0.0*	*0.0*	0.0031	0.7	0.3	0.0072	0.8	0.3	0.0002	0.2	0.1
Mo	*0.0000*	*0.0*	*0.0*	0.0002	0.0	0.0	0.0005	0.1	0.0	*0.0000*	*0.0*	*0.0*
Ti	0.0010	1.2	0.5	0.0012	0.3	0.1	0.0014	0.2	0.1	0.0009	0.7	0.4
Li	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*
Sb	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*
Pb	0.0004	0.5	0.2	0.0039	0.9	0.4	0.0082	0.9	0.4	0.0012	1.0	0.5
mg, Metals Found	0.0849	100.0	40.4	0.4383	100.0	43.8	0.8846	100.0	41.5	0.1230	100.0	49.2
mg, Filter Loading	0.2100			1.0000			2.1300			0.2500		

Table A2.9A.8 Test 2/9A Marple #2 Elemental Analyses, Stages 8-9

2/9A	STAGE 8			STAGE 9								
#2937	Particle size 0.52 µm			Particle size final, 0.25 µm								
	mg	% detected	% loading	mg	% detected	% loading						
Ce	0.0033	5.5	16.5	0.0014	5.2	0.9						
Cu	0.0192	31.7	96.0	0.0085	31.5	5.7						
Zr	0.0020	3.3	10.0	0.0027	10.0	1.8						
Fe	0.0324	53.6	162.0	0.0118	43.7	7.9						
Al	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*						
Mg	*0.0000*	*0.0*	*0.0*	0.0019	7.0	1.3						
Cr	0.0005	0.8	2.5	0.0001	0.4	0.1						
Ni	0.0003	0.5	1.5	0.0001	0.4	0.1						
Mn	0.0005	0.8	2.5	0.0001	0.4	0.1						
Sn	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*						
Mo	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*						
Ti	0.0008	1.3	4.0	0.0002	0.7	0.1						
Li	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*						
Sb	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*						
Pb	0.0004	0.7	2.0	0.0002	0.7	0.1						
mg, Metals Found	0.0605	100.0	302.5	0.0270	100.0	18.0						
mg, Filter Loading	0.0200			0.1500								

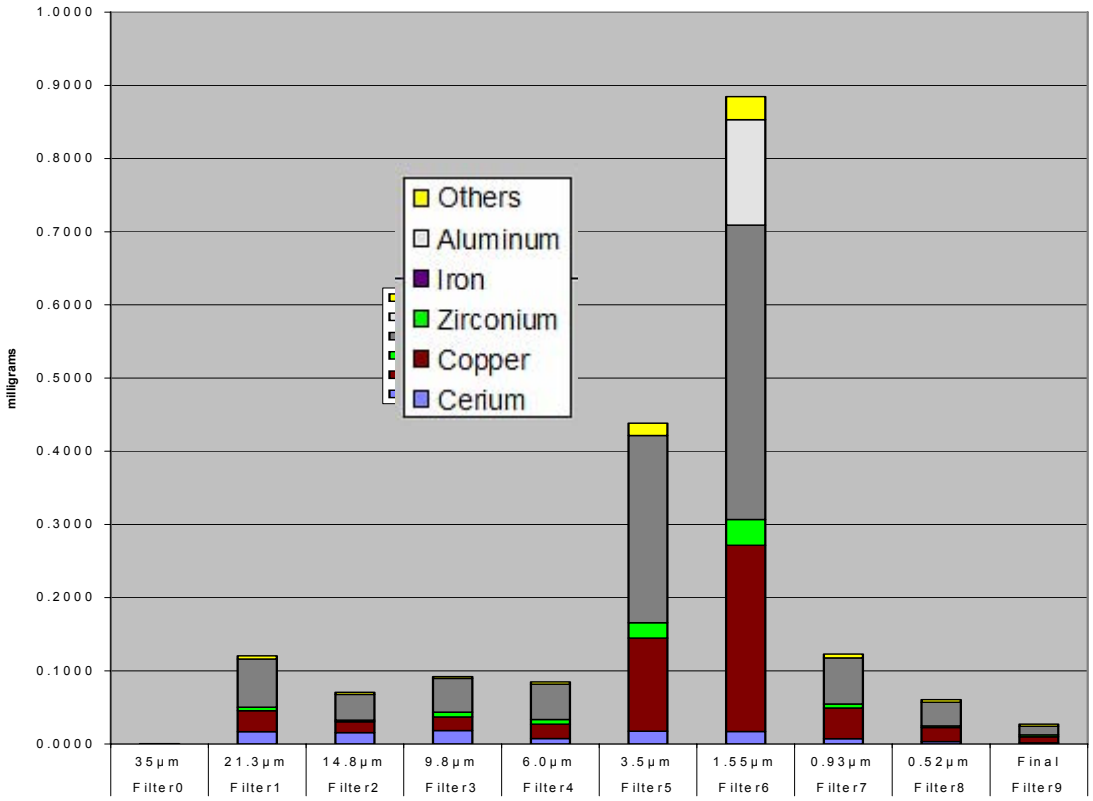


Figure A2.9A.7 Test 2/9A Marple #2 Metals Analysis Distribution, mg

Table A2.9A.9 Test 2/9A Marple #4 Elemental Analyses, Stages 0-3

2/9A	STAGE 0			STAGE 1			STAGE 2			STAGE 3		
#2941	Particle size 35 µm			Particle size 21.3 µm			Particle size 14.8 µm			Particle size 9.8 µm		
	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading
Ce	0.0161	8.7	1.4	0.0095	16.4	5.6	0.0070	16.5	5.0	0.0126	24.5	25.2
Cu	0.0548	29.6	4.6	0.0154	26.6	9.1	0.0112	26.5	8.0	0.0109	21.2	21.8
Zr	0.0099	5.3	0.8	0.0012	2.1	0.7	*0.0000*	*0.0*	*0.0*	0.0017	3.3	3.4
Fe	0.0979	52.8	8.3	0.0296	51.0	17.4	0.0220	52.0	15.7	0.0246	47.9	49.2
Al	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*
Mg	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*
Cr	0.0014	0.8	0.1	0.0005	0.9	0.3	0.0005	1.2	0.4	0.0004	0.8	0.8
Ni	0.0009	0.5	0.1	0.0002	0.3	0.1	0.0003	0.7	0.2	0.0002	0.4	0.4
Mn	0.0015	0.8	0.1	0.0004	0.7	0.2	0.0003	0.7	0.2	0.0003	0.6	0.6
Sn	0.0006	0.3	0.1	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*
Mo	0.0002	0.1	0.0	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*
Ti	0.0006	0.3	0.1	0.0009	1.6	0.5	0.0007	1.7	0.5	0.0006	1.2	1.2
Li	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*
Sb	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*	*0.0000*	*0.0*	*0.0*
Pb	0.0014	0.8	0.1	0.0003	0.5	0.2	0.0002	0.5	0.1	0.0001	0.2	0.2
mg, Metals Found	0.1853	100.0	15.7	0.0580	100.0	34.1	0.0423	100.0	30.2	0.0514	100.0	102.8
mg, Filter Loading	1.1800			0.1700			0.1400			0.0500		

Table A2.9A.10 Test 2/9A Marple #4 Elemental Analyses, Stages 4-7

2/9A	STAGE 4			STAGE 5			STAGE 6			STAGE 7		
#2941	Particle size 6.0 µm			Particle size 3.5 µm			Particle size 1.55 µm			Particle size 0.93 µm		
	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading
Ce	0.0114	20.3	38.0	0.0136	11.4	5.4	0.0115	3.1	1.0	0.0078	4.4	3.1
Cu	0.0114	20.3	38.0	0.0336	28.2	13.4	0.1392	37.0	12.7	0.0472	26.7	18.9
Zr	0.0024	4.3	8.0	0.0071	6.0	2.8	0.0175	4.7	1.6	0.0053	3.0	2.1
Fe	0.0280	49.9	93.3	0.0608	51.0	24.3	0.1927	51.2	17.5	0.0708	40.0	28.3
Al	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0402	22.7	16.1
Mg	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Cr	0.0004	0.7	1.3	0.0008	0.7	0.3	0.0023	0.6	0.2	0.0010	0.6	0.4
Ni	0.0002	0.4	0.7	0.0005	0.4	0.2	0.0017	0.5	0.2	0.0006	0.3	0.2
Mn	0.0003	0.5	1.0	0.0009	0.8	0.4	0.0034	0.9	0.3	0.0012	0.7	0.5
Sn	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0030	0.8	0.3	0.0003	0.2	0.1
Mo	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0003	0.1	0.0	0.0001	0.1	0.0
Ti	0.0015	2.7	5.0	0.0008	0.7	0.3	0.0007	0.2	0.1	0.0009	0.5	0.4
Li	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0001	0.1	0.0
Sb	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Pb	0.0002	0.4	0.7	0.0008	0.7	0.3	0.0040	1.1	0.4	0.0013	0.7	0.5
mg, Metals Found	0.0561	100.0	187.0	0.1191	100.0	47.6	0.3763	100.0	34.2	0.1770	100.0	70.8
mg, Filter Loading	0.0300			0.2500			1.1000			0.2500		

Table A2.9A.11 Test 2/9A Marple #4 Elemental Analyses, Stages 8-9

2/9A	STAGE 8			STAGE 9								
#2941	Particle size 0.52 µm			Particle size final, 0.25 µm								
	mg	% detected	% loading	mg	% detected	% loading						
Ce	0.0070	5.3	2.6	0.0038	4.7	0.6						
Cu	0.0455	34.5	16.9	0.0216	26.6	3.5						
Zr	0.0073	5.5	2.7	0.0078	9.6	1.3						
Fe	0.0613	46.4	22.7	0.0427	52.6	7.0						
Al	0.0058	4.4	2.1	0.0000	0.0	0.0						
Mg	0.0000	0.0	0.0	0.0032	3.9	0.5						
Cr	0.0008	0.6	0.3	0.0002	0.2	0.0						
Ni	0.0005	0.4	0.2	0.0002	0.2	0.0						
Mn	0.0010	0.8	0.4	0.0005	0.6	0.1						
Sn	0.0004	0.3	0.1	0.0000	0.0	0.0						
Mo	0.0001	0.1	0.0	0.0000	0.0	0.0						
Ti	0.0008	0.6	0.3	0.0006	0.7	0.1						
Li	0.0000	0.0	0.0	0.0000	0.0	0.0						
Sb	0.0000	0.0	0.0	0.0000	0.0	0.0						
Pb	0.0012	0.9	0.4	0.0006	0.7	0.1						
mg, Metals Found	0.1320	100.0	48.9	0.0812	100.0	13.3						
mg, Filter Loading	0.2700			0.6100								

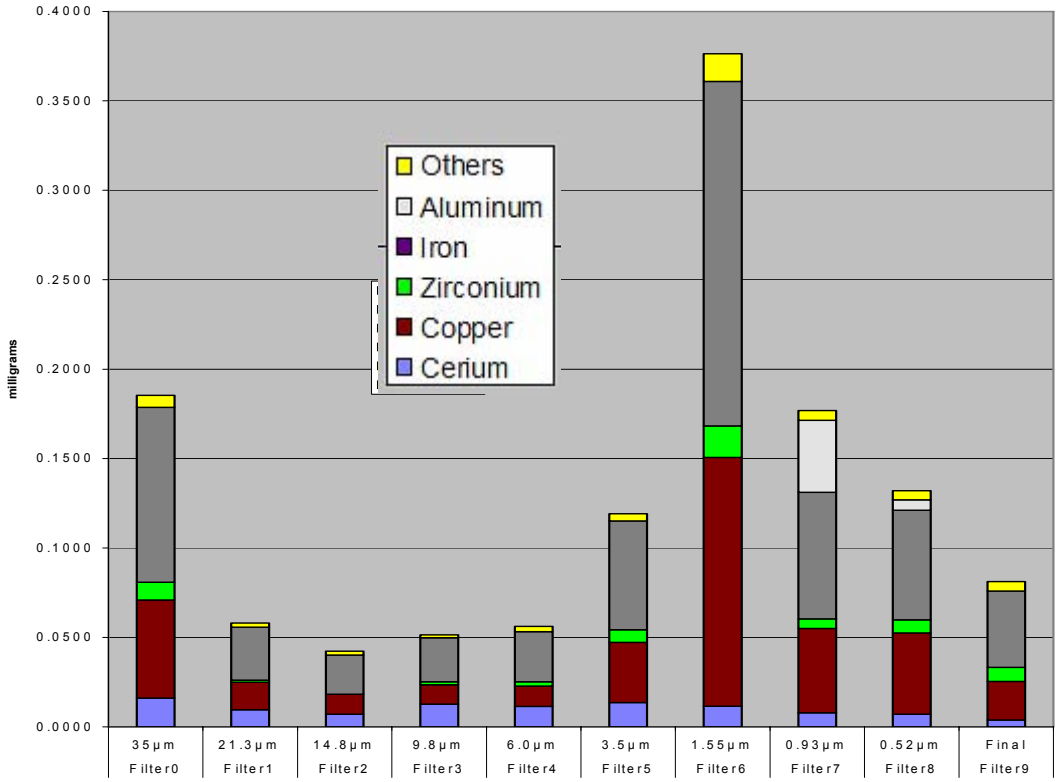


Figure A2.9A.8 Test 2/9A Marple #4 Metals Analysis Distribution, mg

A.2.9B Test 2/9B Analyses and Results

Graphs of gravimetric particle size distributions from the four 2/9B Marple impactors, plus the mass concentrations, were presented in Figures A1.9.6 – A1.9.10 in [Molecke et al., 2005a].

Eight separate impact particle debris samples were collected by a HEPA vacuum system from various sample points within the top aerosol chamber; multiple samples were mandated because the HEPA vacuum filter sock collector became clogged and needed to be replaced. Changes in this HEPA vacuum system will be implemented in the future to resolve this problem. The multiple sample points in the chamber were specified only as "Floor #1 – Floor #6 and Sides/Top #1 and #2." Each set of particle debris was weighed separately and then sieved using a set of 48mm-diameter sieves; 1000 µm, 500 µm, 250 µm, and 125 µm (geometric) with a final catch pan. The 'fines' were then sieved further with disposable mesh sieves at 100 µm, 74 µm, 37 µm, and 25 µm to further differentiate the debris. These particle debris sample weights are summarized in Table A2.9B.12.

The impact debris elemental analysis for the Floor #1 sample is listed in Table A2.9B.13. The weight % distribution of major metals in this impact debris is shown in Figure A2.9B.9. The elemental results for the Floor #2-#6 and Sides/Top #1-#2 samples are very similar and not listed.

Marple Particle Element Analyses: Particulates were sampled using four independent Large Particle Separator (LPS) and Marple impactor systems. Chemical analyses were made for all four sampling sytems. For test 2/9B, each of the four LPS fiberglass subtrates, nominally covering the particle size range of 30 to 100 µm AED was chemically digested in total for individual chemical elemental analyses by ICP-MS.

Table A2.9B.12 Test 2/9B Weight Distribution of Impact Debris

Sieve Fraction	Floor #1	Floor #2	Floor #3	Floor #4	Floor #5	Floor #6	Side/Top #1	Side/Top #2	Totals
(geometric)	weight, g	weight, g	weight, g	weight, g	weight, g	weight, g	weight, g	weight, g	weight, g
1000 µm	0.0655	0.0543	0.0406	0.3303	4.2098	3.0542	0.0023	0.0465	7.8035
500 µm	0.0631	0.0804	0.1232	0.3127	0.9216	0.1047	0.0139	0.0288	1.6484
250 µm	0.1432	0.2182	0.3444	0.7798	0.6673	0.0644	0.0451	0.0364	2.2988
125 µm	0.3695	0.5892	0.6831	1.1803	0.3342	0.0779	0.1418	0.0353	3.4113
100 µm	0.2193	0.421	0.4562	0.5304	0.0966	0.053	0.1192	0.0236	1.9193
74 µm	0.3239	0.6266	0.5662	0.6109	0.0584	0.0431	0.1384	0.0372	2.4047
37 µm	3.4914	3.645	2.2318	2.242	0.1584	0.1556	1.5165	0.142	13.5827
25 µm	0.8269	0.3353	1.0405	1.368	0.0341	0.0449	1.1894	0.0354	4.8745
<25 µm	0.7604	0.2745	0.4536	0.6286	0.1464	0.1264	0.4013	0.2106	3.0018
Total	6.2632	6.2445	5.9396	7.983	6.6268	3.7242	3.5679	0.5958	**40.9450**

Table A2.9B.13 Test 2/9B Elemental Analysis Wt% of Floor #1 Sieved Impact Debris

Test 2/9B Sieve Fraction	125 µm	100 µm	74 µm	37 µm	25 µm	<25 µm
Cerium	31.560	37.320	39.790	34.860	31.930	36.850
Iron	26.720	23.320	19.910	14.490	13.980	12.990
Copper	7.258	7.427	7.218	6.360	5.810	5.402
Zirconium	7.248	3.857	2.915	1.078	1.907	1.626
Aluminum	2.605	3.252	4.036	10.180	12.460	10.710
Manganese	0.932	0.493	0.357	0.214	0.196	0.171
Tin	0.078	0.054	0.042	0.041	0.045	0.034
Chromium	0.112	0.116	0.076	0.067	0.070	0.056
Magnesium	0.027	0.046	0.050	0.134	0.175	0.154
Nickel	0.035	0.041	0.031	0.031	0.034	0.028
Titanium	0.138	0.099	0.060	0.044	0.046	0.034
Molybdenum	0.005	0.006	0.004	0.003	0.004	0.003
Lead	0.013	0.017	0.017	0.037	0.042	0.034
Hafnium	0.003	0.001	<0.001	<0.001	<0.001	<0.001
Barium	0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Total *	76.739	76.054	74.511	67.543	66.703	68.097

* includes “minor” lanthanides: Lanthanum, Praeseodymium, Neodymium; Terbium at 0.004

All Marple #1 particle elemental analyses are listed in Tables A2.9B.14 to A2.9B.16 and are plotted in Figure A2.9B.10. LPS samples #1 through #4 particle elemental analyses are listed in Table A2.9B.17 and plotted in Figure A2.9B.11. Similarly, all Marple #2 elemental analyses are listed in Tables A2.9B.18 to A2.9B.20 and are plotted in Figure A2.9B.12; all Marple #3 elemental analyses are listed in Tables A2.9B.21 to A2.9B.23 and are plotted in Figure A2.9B.13; and, all Marple #4 elemental analyses are listed in Tables A2.9B.24 to A2.9B.26 and are plotted in Figure A2.9B.14.

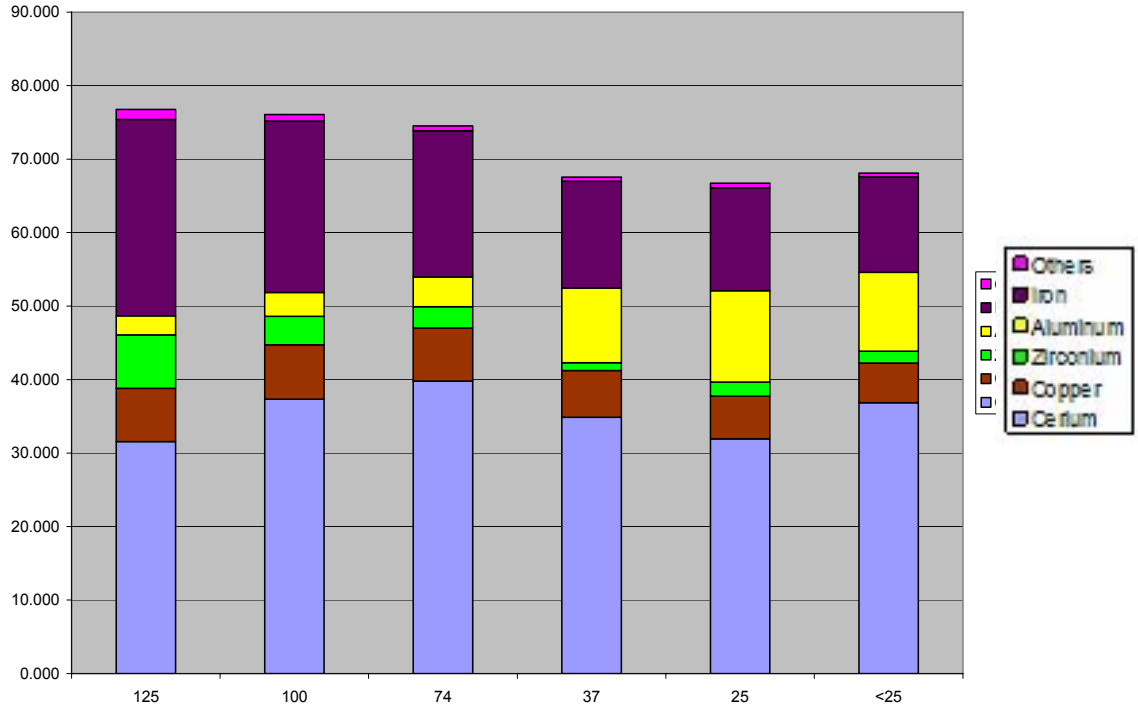


Figure A2.9B.9 Test 2/9B Weight % Distribution of Major Metals in Floor #1 Impact Debris

Table A2.9B.14 Test 2/9B Marple #1 Elemental Analyses, Stages 0-3

2/9B	STAGE 0			STAGE 1			STAGE 2			STAGE 3		
#2935	Particle size 35 µm			Particle size 21.3 µm			Particle size 14.8 µm			Particle size 9.8 µm		
	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading
Ce	0.1613	36.7	15.2	0.0101	5.1	0.8	0.0162	10.7	1.7	0.0147	5.8	0.5
Cu	0.0672	15.3	6.3	0.0513	25.8	3.9	0.0365	24.0	3.7	0.0645	25.6	2.3
Zr	0.0253	5.8	2.4	0.0167	8.4	1.3	0.0099	6.5	1.0	0.0175	7.0	0.6
Fe	0.1761	40.1	16.6	0.1152	58.0	8.7	0.0855	56.2	8.7	0.1489	59.2	5.4
Al	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Mg	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Cr	0.0032	0.7	0.3	0.0013	0.7	0.1	0.0009	0.6	0.1	0.0014	0.6	0.1
Ni	0.0012	0.3	0.1	0.0007	0.4	0.1	0.0005	0.3	0.1	0.0008	0.3	0.0
Mn	0.0028	0.6	0.3	0.0018	0.9	0.1	0.0013	0.9	0.1	0.0022	0.9	0.1
Sn	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Mo	0.0002	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Ti	0.0019	0.4	0.2	0.0012	0.6	0.1	0.0013	0.9	0.1	0.0013	0.5	0.0
Li	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Sb	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Pb	0.0004	0.1	0.0	0.0002	0.1	0.0	0.0000	0.0	0.0	0.0003	0.1	0.0
mg, Metals Found	0.4396	100.0	41.5	0.1985	100.0	14.9	0.1521	100.0	15.5	0.2516	100.0	9.1
mg, Filter Loading	1.0600			1.3300			0.9800			2.7700		

Table A2.9B.15 Test 2/9B Marple #1 Elemental Analyses, Stages 4-7

2/9B	STAGE 4			STAGE 5			STAGE 6			STAGE 7		
#2935	Particle size 6.0 µm			Particle size 3.5 µm			Particle size 1.55 µm			Particle size 0.93 µm		
	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading
Ce	0.0104	2.5	0.4	0.0522	10.2	2.0	0.0084	3.9	0.7	0.0080	12.4	2.2
Cu	0.1014	24.2	3.9	0.1234	24.1	4.7	0.0638	29.3	5.4	0.0204	31.7	5.7
Zr	0.0425	10.2	1.6	0.0617	12.1	2.3	0.0244	11.2	2.1	0.0046	7.1	1.3
Fe	0.2260	54.0	8.6	0.2514	49.2	9.6	0.1133	52.1	9.6	0.0274	42.5	7.6
Al	0.0281	6.7	1.1	0.0092	1.8	0.3	0.0000	0.0	0.0	0.0000	0.0	0.0
Mg	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Cr	0.0022	0.5	0.1	0.0028	0.5	0.1	0.0015	0.7	0.1	0.0009	1.4	0.3
Ni	0.0012	0.3	0.0	0.0015	0.3	0.1	0.0007	0.3	0.1	0.0005	0.8	0.1
Mn	0.0035	0.8	0.1	0.0046	0.9	0.2	0.0027	1.2	0.2	0.0009	1.4	0.3
Sn	0.0000	0.0	0.0	0.0004	0.1	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Mo	0.0000	0.0	0.0	0.0001	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Ti	0.0022	0.5	0.1	0.0026	0.5	0.1	0.0021	1.0	0.2	0.0013	2.0	0.4
Li	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Sb	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Pb	0.0007	0.2	0.0	0.0012	0.2	0.0	0.0007	0.3	0.1	0.0001	0.2	0.0
mg, Metals Found	0.4182	100.0	15.9	0.5111	100.0	19.4	0.2176	100.0	18.4	0.0644	100.0	17.9
mg, Filter Loading	2.6300			2.6300			1.1800			0.3600		

Table A2.9B.16 Test 2/9B Marple #1 Elemental Analyses, Stages 8-9

2/9B	STAGE 8			STAGE 9								
#2935	Particle size 0.52 µm			Particle size final, 0.25 µm								
	mg	% detected	% loading	mg	% detected	% loading						
Ce	0.0061	23.6	8.7	0.0017	12.6	1.2						
Cu	0.0096	37.2	13.7	0.0058	43.0	4.1						
Zr	0.0000	0.0	0.0	0.0014	10.4	1.0						
Fe	0.0071	27.5	10.1	0.0028	20.7	2.0						
Al	0.0000	0.0	0.0	0.0000	0.0	0.0						
Mg	0.0000	0.0	0.0	0.0000	0.0	0.0						
Cr	0.0004	1.6	0.6	0.0001	0.7	0.1						
Ni	0.0001	0.4	0.1	0.0000	0.0	0.0						
Mn	0.0005	1.9	0.7	0.0004	3.0	0.3						
Sn	0.0000	0.0	0.0	0.0000	0.0	0.0						
Mo	0.0000	0.0	0.0	0.0000	0.0	0.0						
Ti	0.0014	5.4	2.0	0.0010	7.4	0.7						
Li	0.0000	0.0	0.0	0.0000	0.0	0.0						
Sb	0.0000	0.0	0.0	0.0000	0.0	0.0						
Pb	0.0000	0.0	0.0	0.0001	0.7	0.1						
mg, Metals Found	0.0258	100.0	36.9	0.0135	100.0	9.6						
mg, Filter Loading	0.0700			0.1400								

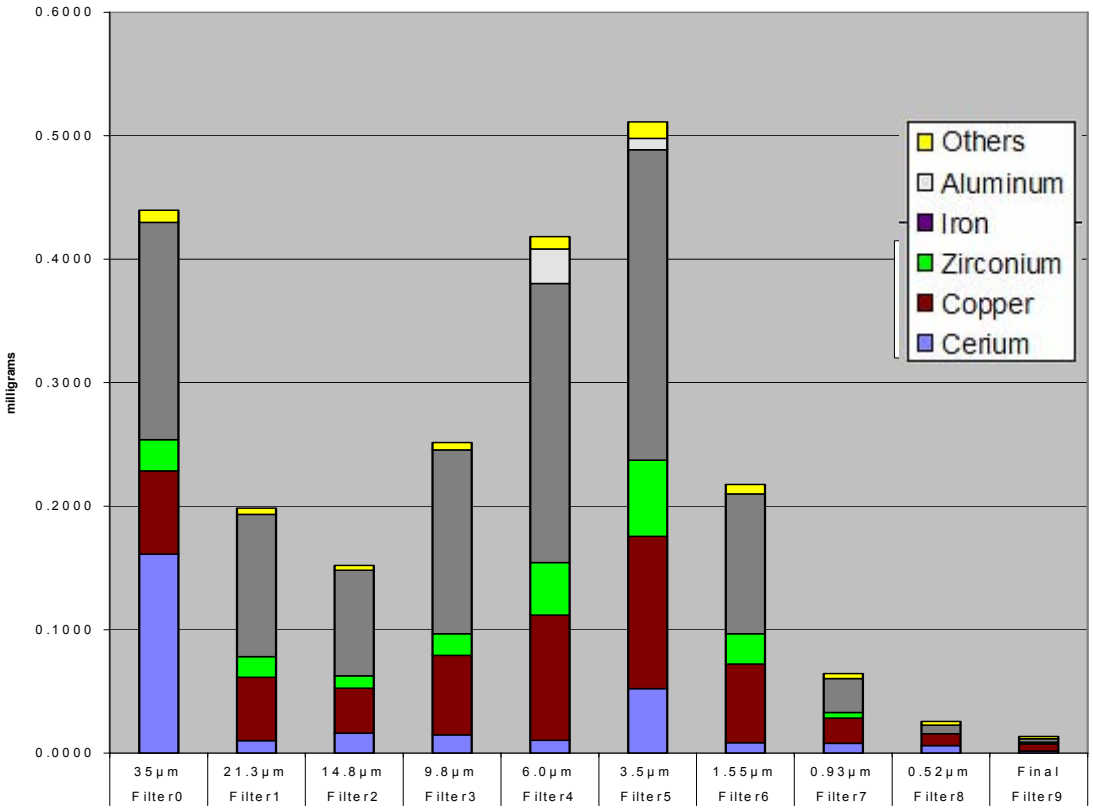


Figure A2.9B.10 Test 2/9B Marple #1 Metals Analysis Distribution, mg

Table A2.9B.17 Test 2/9B LPS #1 to #4 Particle Elemental Analyses Weight %

Test 2/9B Weight %	**LPS #1** (ID 2935)	**LPS #2** (2937)	**LPS #3** (2938)	**LPS #4** (2941)
Cerium	30.710	29.950	31.350	33.740
Iron	12.650	14.930	14.090	14.580
Copper	5.838	5.147	6.999	5.952
Zirconium	1.886	1.827	1.960	1.948
Aluminum	9.574	6.088	10.050	8.772
Manganese	0.192	0.190	0.186	0.193
Tin	0.044	0.038	0.043	0.043
Chromium	0.123	0.123	0.134	0.117
Magnesium	0.178	0.174	0.204	0.173
Nickel	0.063	0.062	0.058	0.058
Titanium	0.062	0.056	0.065	0.062
Molybdenum	0.005	0.017	0.005	0.006
Lead	0.032	0.025	0.029	0.028
Hafnium	<0.001	<0.001	<0.001	<0.001
Barium	0.004	0.001	0.000	0.004
Total *	61.368	58.633	65.179	65.684

* includes minor lanthanides

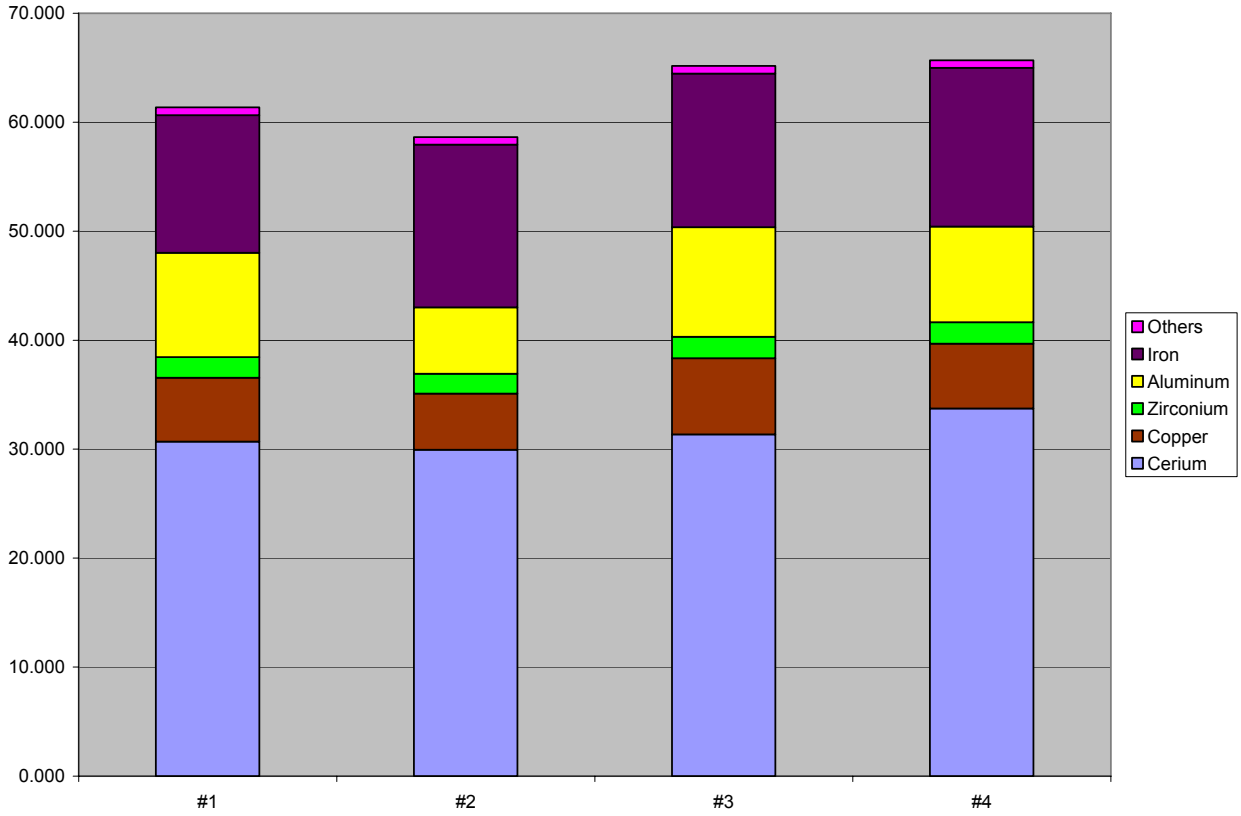


Figure A2.9B.11 Test 2/9B LPS #1 - #4 Weight Percent Metals Analysis Distribution

Table A2.9B.18 Test 2/9B Marple #2 Elemental Analyses, Stages 0-3

2/9B	STAGE 0			STAGE 1			STAGE 2			STAGE 3		
#2937	Particle size 35 µm			Particle size 21.3 µm			Particle size 14.8 µm			Particle size 9.8 µm		
	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading
Ce	0.0254	9.0	2.1	0.0113	6.4	1.4	0.0190	13.8	3.0	0.0169	6.9	0.7
Cu	0.0701	24.9	5.8	0.0423	24.1	5.4	0.0298	21.7	4.7	0.0569	23.4	2.4
Zr	0.0237	8.4	2.0	0.0136	7.8	1.7	0.0084	6.1	1.3	0.0191	7.8	0.8
Fe	0.1554	55.2	13.0	0.1027	58.6	13.2	0.0762	55.5	12.1	0.1445	59.4	6.0
Al	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Mg	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Cr	0.0016	0.6	0.1	0.0012	0.7	0.2	0.0009	0.7	0.1	0.0014	0.6	0.1
Ni	0.0008	0.3	0.1	0.0005	0.3	0.1	0.0004	0.3	0.1	0.0006	0.2	0.0
Mn	0.0024	0.9	0.2	0.0016	0.9	0.2	0.0011	0.8	0.2	0.0021	0.9	0.1
Sn	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Mo	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Ti	0.0017	0.6	0.1	0.0018	1.0	0.2	0.0015	1.1	0.2	0.0016	0.7	0.1
Li	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Sb	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Pb	0.0004	0.1	0.0	0.0002	0.1	0.0	0.0000	0.0	0.0	0.0003	0.1	0.0
mg, Metals Found	0.2815	100.0	23.5	0.1754	100.0	22.5	0.1373	100.0	21.8	0.2434	100.0	10.1
mg, Filter Loading	1.2000			0.7800			0.6300			2.4000		

Table A2.9B.19 Test 2/9B Marple #2 Elemental Analyses, Stages 4-7

2/9B	STAGE 4			STAGE 5			STAGE 6			STAGE 7		
#2937	Particle size 6.0 µm			Particle size 3.5 µm			Particle size 1.55 µm			Particle size 0.93 µm		
	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading
Ce	0.0153	4.3	0.6	0.0207	4.2	0.7	0.0173	6.9	1.5	0.0111	32.1	37.0
Cu	0.0777	21.6	3.1	0.1341	27.4	4.7	0.0738	29.4	6.4	0.0093	26.9	31.0
Zr	0.0333	9.3	1.3	0.0591	12.1	2.1	0.0245	9.8	2.1	0.0000	0.0	0.0
Fe	0.2246	62.5	8.9	0.2618	53.4	9.2	0.1272	50.7	11.1	0.0118	34.1	39.3
Al	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Mg	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Cr	0.0019	0.5	0.1	0.0031	0.6	0.1	0.0017	0.7	0.1	0.0004	1.2	1.3
Ni	0.0010	0.3	0.0	0.0015	0.3	0.1	0.0008	0.3	0.1	0.0001	0.3	0.3
Mn	0.0029	0.8	0.1	0.0050	1.0	0.2	0.0031	1.2	0.3	0.0004	1.2	1.3
Sn	0.0000	0.0	0.0	0.0006	0.1	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Mo	0.0000	0.0	0.0	0.0001	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Ti	0.0021	0.6	0.1	0.0029	0.6	0.1	0.0019	0.8	0.2	0.0013	3.8	4.3
Li	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Sb	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Pb	0.0005	0.1	0.0	0.0013	0.3	0.0	0.0008	0.3	0.1	0.0000	0.0	0.0
mg, Metals Found	0.3593	100.0	14.3	0.4902	100.0	17.1	0.2511	100.0	21.8	0.0346	100.0	115.3
mg, Filter Loading	2.5100			2.8600			1.1500			0.0300		

Table A2.9B.20 Test 2/9B Marple #2 Elemental Analyses, Stages 8-9

2/9B	STAGE 8			STAGE 9								
#2937	Particle size 0.52 µm			Particle size final, 0.25 µm								
	mg	% detected	% loading	mg	% detected	% loading						
Ce	0.0000	0.0	0.0	0.0000	0.0	0.0						
Cu	0.0036	73.5	9.0	0.0032	47.1	3.2						
Zr	0.0000	0.0	0.0	0.0000	0.0	0.0						
Fe	0.0005	10.2	1.3	0.0026	38.2	2.6						
Al	0.0000	0.0	0.0	0.0000	0.0	0.0						
Mg	0.0000	0.0	0.0	0.0000	0.0	0.0						
Cr	0.0003	6.1	0.8	0.0004	5.9	0.4						
Ni	0.0000	0.0	0.0	0.0002	2.9	0.2						
Mn	0.0002	4.1	0.5	0.0002	2.9	0.2						
Sn	0.0000	0.0	0.0	0.0000	0.0	0.0						
Mo	0.0000	0.0	0.0	0.0000	0.0	0.0						
Ti	0.0003	6.1	0.8	0.0002	2.9	0.2						
Li	0.0000	0.0	0.0	0.0000	0.0	0.0						
Sb	0.0000	0.0	0.0	0.0000	0.0	0.0						
Pb	0.0000	0.0	0.0	0.0000	0.0	0.0						
mg, Metals Found	0.0049	100.0	12.3	0.0068	100.0	6.8						
mg, Filter Loading	0.0400			0.1000								

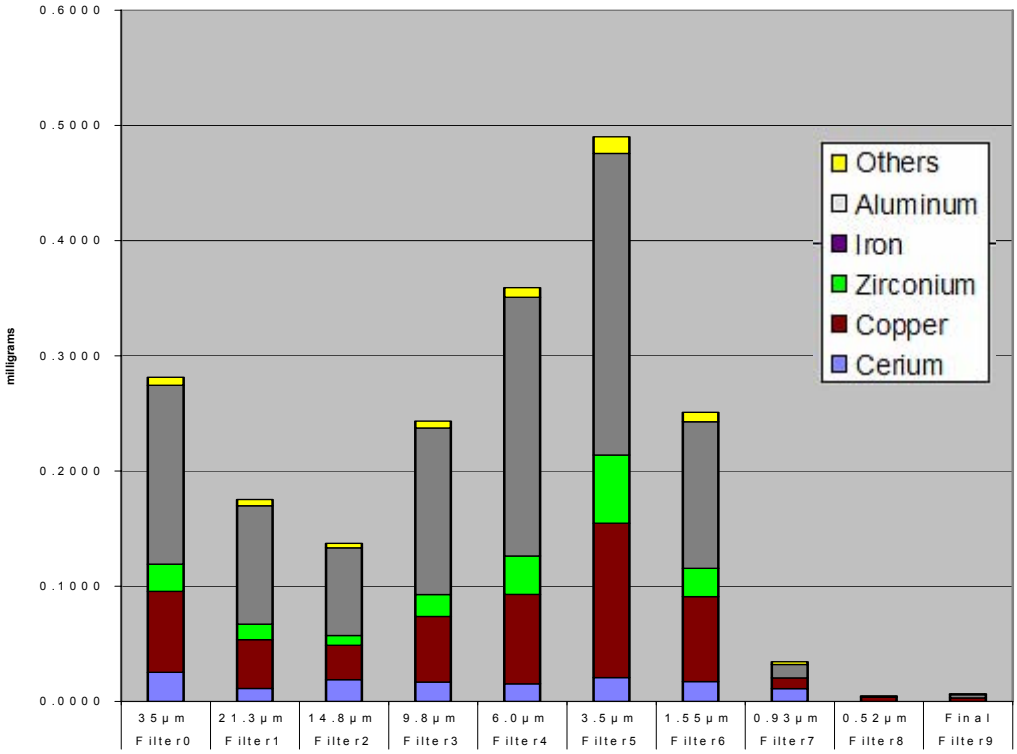


Figure A2.9B.12 Test 2/9B Marple #2 Metals Analysis Distribution, mg

Table A2.9B.21 Test 2/9B Marple #3 Elemental Analyses, Stages 0-3

2/9B	STAGE 0			STAGE 1			STAGE 2			STAGE 3		
#2938	Particle size 35 µm			Particle size 21.3 µm			Particle size 14.8 µm			Particle size 9.8 µm		
	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading
Ce	0.0143	3.2	1.2	0.0197	8.6	1.6	0.0178	8.7	1.6	0.0195	5.3	0.6
Cu	0.0993	22.2	8.3	0.0497	21.8	4.0	0.0439	21.4	3.9	0.0895	24.4	2.8
Zr	0.0340	7.6	2.8	0.0168	7.4	1.4	0.0128	6.3	1.1	0.0297	8.1	0.9
Fe	0.2629	58.9	21.9	0.1351	59.3	11.0	0.1245	60.8	10.9	0.2199	59.9	6.9
Al	0.0245	5.5	2.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Mg	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Cr	0.0032	0.7	0.3	0.0020	0.9	0.2	0.0015	0.7	0.1	0.0023	0.6	0.1
Ni	0.0015	0.3	0.1	0.0009	0.4	0.1	0.0007	0.3	0.1	0.0012	0.3	0.0
Mn	0.0037	0.8	0.3	0.0018	0.8	0.1	0.0016	0.8	0.1	0.0030	0.8	0.1
Sn	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Mo	0.0001	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Ti	0.0022	0.5	0.2	0.0016	0.7	0.1	0.0017	0.8	0.1	0.0017	0.5	0.1
Li	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Sb	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Pb	0.0006	0.1	0.1	0.0002	0.1	0.0	0.0002	0.1	0.0	0.0005	0.1	0.0
mg, Metals Found	0.4463	100.0	37.2	0.2278	100.0	18.5	0.2047	100.0	18.0	0.3673	100.0	11.5
mg, Filter Loading	1.2000			1.2300			1.1400			3.1900		

Table A2.9B.22 Test 2/9B Marple #3 Elemental Analyses, Stages 4-7

2/9B	STAGE 4			STAGE 5			STAGE 6			STAGE 7		
#2938	Particle size 6.0 µm			Particle size 3.5 µm			Particle size 1.55 µm			Particle size 0.93 µm		
	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading
Ce	0.0275	4.8	0.9	0.0170	2.9	0.6	0.0129	6.3	1.3	0.0105	31.8	6.6
Cu	0.1170	20.4	3.7	0.1371	23.0	4.4	0.0526	25.8	5.3	0.0102	30.9	6.4
Zr	0.0483	8.4	1.5	0.0592	9.9	1.9	0.0165	8.1	1.7	0.0000	0.0	0.0
Fe	0.3050	53.1	9.7	0.2928	49.2	9.5	0.0931	45.7	9.4	0.0106	32.1	6.6
Al	0.0650	11.3	2.1	0.0742	12.5	2.4	0.0201	9.9	2.0	0.0000	0.0	0.0
Mg	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Cr	0.0027	0.5	0.1	0.0032	0.5	0.1	0.0012	0.6	0.1	0.0003	0.9	0.2
Ni	0.0014	0.2	0.0	0.0015	0.3	0.0	0.0005	0.2	0.1	0.0001	0.3	0.1
Mn	0.0042	0.7	0.1	0.0052	0.9	0.2	0.0023	1.1	0.2	0.0004	1.2	0.3
Sn	0.0000	0.0	0.0	0.0005	0.1	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Mo	0.0001	0.0	0.0	0.0001	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Ti	0.0027	0.5	0.1	0.0032	0.5	0.1	0.0023	1.1	0.2	0.0009	2.7	0.6
Li	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0012	0.6	0.1	0.0000	0.0	0.0
Sb	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0002	0.1	0.0	0.0000	0.0	0.0
Pb	0.0009	0.2	0.0	0.0015	0.3	0.0	0.0006	0.3	0.1	0.0000	0.0	0.0
mg, Metals Found	0.5748	100.0	18.4	0.5955	100.0	19.3	0.2035	100.0	20.6	0.0330	100.0	20.6
mg, Filter Loading	3.1300			3.0900			0.9900			0.1600		

Table A2.9B.23 Test 2/9B Marple #3 Elemental Analyses, Stages 8-9

2/9B	STAGE 8			STAGE 9								
#2938	Particle size 0.52 µm			Particle size final, 0.25 µm								
	mg	% detected	% loading	mg	% detected	% loading						
Ce	0.0035	16.4	8.8	0.0031	14.6	14.6						
Cu	0.0081	37.9	20.3	0.0060	28.2	28.2						
Zr	0.0000	0.0	0.0	0.0004	1.9	1.9						
Fe	0.0075	35.0	18.8	0.0091	42.7	42.7						
Al	0.0000	0.0	0.0	0.0000	0.0	0.0						
Mg	0.0000	0.0	0.0	0.0000	0.0	0.0						
Cr	0.0004	1.9	1.0	0.0006	2.8	2.8						
Ni	0.0001	0.5	0.3	0.0003	1.4	1.4						
Mn	0.0005	2.3	1.3	0.0004	1.9	1.9						
Sn	0.0000	0.0	0.0	0.0000	0.0	0.0						
Mo	0.0000	0.0	0.0	0.0000	0.0	0.0						
Ti	0.0012	5.6	3.0	0.0013	6.1	6.1						
Li	0.0000	0.0	0.0	0.0000	0.0	0.0						
Sb	0.0000	0.0	0.0	0.0000	0.0	0.0						
Pb	0.0000	0.0	0.0	0.0001	0.5	0.5						
mg, Metals Found	0.0214	100.0	53.5	0.0213	100.0	100.0						
mg, Filter Loading	0.0400			0.0213								

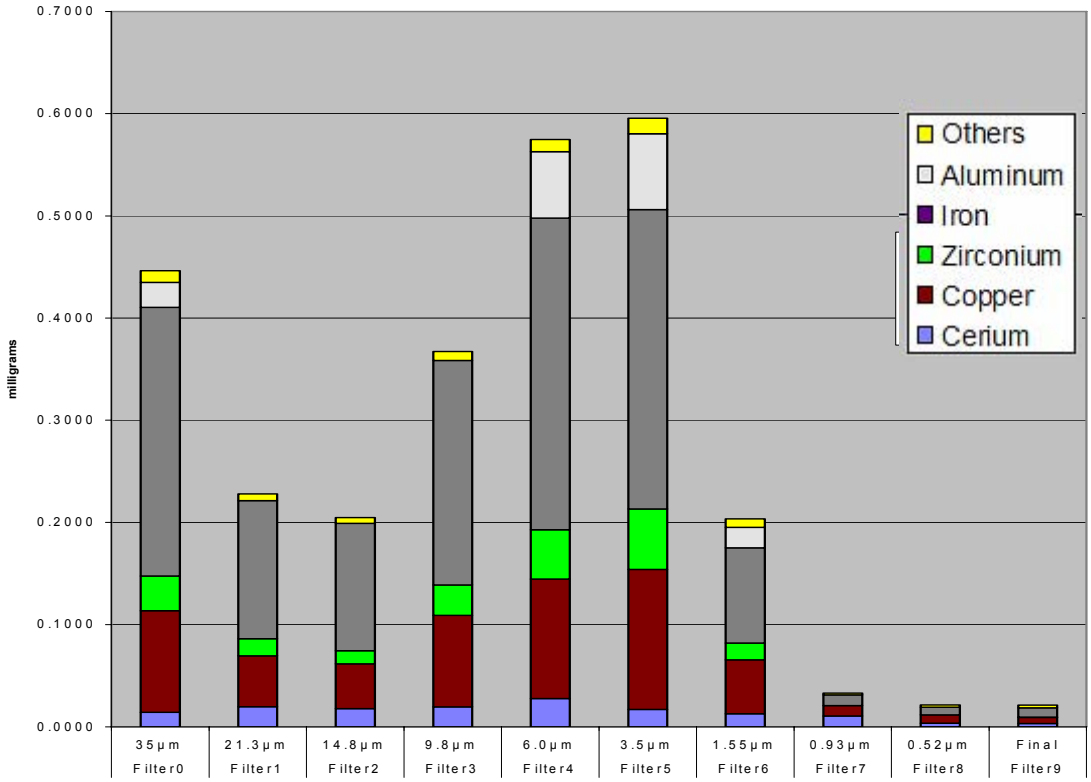


Figure A2.9B.13 Test 2/9B Marple #3 Metals Analysis Distribution, mg

Table A2.9B.24 Test 2/9B Marple #4 Elemental Analyses, Stages 0-3

2/9B	STAGE 0			STAGE 1			STAGE 2			STAGE 3		
#2941	Particle size 35 µm			Particle size 21.3 µm			Particle size 14.8 µm			Particle size 9.8 µm		
	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading
Ce	0.0746	14.3	3.0	0.0453	16.1	151.0	0.0529	34.0	8.8	0.0385	14.4	2.0
Cu	0.1067	20.4	4.3	0.0516	18.3	172.0	0.0277	17.8	4.6	0.0533	19.9	2.8
Zr	0.0394	7.5	1.6	0.0177	6.3	59.0	0.0078	5.0	1.3	0.0186	7.0	1.0
Fe	0.2496	47.8	10.1	0.1574	55.9	524.7	0.0630	40.5	10.5	0.1513	56.6	8.0
Al	0.0409	7.8	1.7	0.0034	1.2	11.3	0.0000	0.0	0.0	0.0000	0.0	0.0
Mg	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Cr	0.0026	0.5	0.1	0.0015	0.5	5.0	0.0012	0.8	0.2	0.0014	0.5	0.1
Ni	0.0013	0.2	0.1	0.0007	0.2	2.3	0.0005	0.3	0.1	0.0007	0.3	0.0
Mn	0.0040	0.8	0.2	0.0020	0.7	6.7	0.0010	0.6	0.2	0.0019	0.7	0.1
Sn	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Mo	0.0001	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Ti	0.0025	0.5	0.1	0.0018	0.6	6.0	0.0013	0.8	0.2	0.0016	0.6	0.1
Li	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Sb	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Pb	0.0007	0.1	0.0	0.0002	0.1	0.7	0.0000	0.0	0.0	0.0002	0.1	0.0
mg, Metals Found	0.5224	100.0	21.2	0.2816	100.0	938.7	0.1554	100.0	25.9	0.2675	100.0	14.2
mg, Filter Loading	2.4600			0.0300			0.6000			1.8800		

Table A2.9B.25 Test 2/9B Marple #4 Elemental Analyses, Stages 4-7

2/9B	STAGE 4			STAGE 5			STAGE 6			STAGE 7		
#2941	Particle size 6.0 µm			Particle size 3.5 µm			Particle size 1.55 µm			Particle size 0.93 µm		
	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading	mg	% detected	% loading
Ce	0.0800	22.0	3.8	0.0497	9.0	2.2	0.0355	15.5	5.5	0.0268	28.9	9.9
Cu	0.0679	18.7	3.2	0.1088	19.7	4.9	0.0384	16.8	5.9	0.0160	17.2	5.9
Zr	0.0276	7.6	1.3	0.0530	9.6	2.4	0.0148	6.5	2.3	0.0043	4.6	1.6
Fe	0.1805	49.7	8.6	0.2753	49.8	12.4	0.0926	40.6	14.2	0.0297	32.0	11.0
Al	0.0000	0.0	0.0	0.0542	9.8	2.4	0.0414	18.1	6.4	0.0120	12.9	4.4
Mg	0.0000	0.0	0.0	*0.0000*	*0.0*	*0.0*	0.0000	0.0	0.0	0.0000	0.0	0.0
Cr	0.0017	0.5	0.1	0.0025	0.5	0.1	0.0010	0.4	0.2	0.0006	0.6	0.2
Ni	0.0009	0.2	0.0	0.0013	0.2	0.1	0.0004	0.2	0.1	0.0002	0.2	0.1
Mn	0.0024	0.7	0.1	0.0041	0.7	0.2	0.0016	0.7	0.2	0.0008	0.9	0.3
Sn	0.0000	0.0	0.0	0.0004	0.1	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Mo	0.0001	0.0	0.0	0.0001	0.0	0.0	0.0000	0.0	0.0	0.0000	0.0	0.0
Ti	0.0016	0.4	0.1	0.0028	0.5	0.1	0.0017	0.7	0.3	0.0017	1.8	0.6
Li	0.0000	0.0	0.0	*0.0000*	*0.0*	*0.0*	0.0000	0.0	0.0	0.0000	0.0	0.0
Sb	0.0000	0.0	0.0	*0.0000*	*0.0*	*0.0*	0.0000	0.0	0.0	0.0000	0.0	0.0
Pb	0.0004	0.1	0.0	0.0010	0.2	0.0	0.0003	0.1	0.0	0.0000	0.0	0.0
mg, Metals Found	0.3631	100.0	17.3	0.5532	100.0	24.9	0.2283	100.0	35.1	0.0928	100.0	34.4
mg, Filter Loading	2.1000			2.2200			0.6500			0.2700		

Table A2.9B.26 Test 2/9B Marple #4 Elemental Analyses, Stages 8-9

2/9B	STAGE 8			STAGE 9								
#2941	Particle size 0.52 µm			Particle size final, 0.25 µm								
	mg	% detected	% loading	mg	% detected	% loading						
Ce	0.0097	10.1	5.1	0.0029	9.5	2.4						
Cu	0.0118	12.3	6.2	0.0084	27.6	7.0						
Zr	0.0007	0.7	0.4	0.0018	5.9	1.5						
Fe	0.0167	17.4	8.8	0.0102	33.6	8.5						
Al	0.0530	55.1	27.9	0.0000	0.0	0.0						
Mg	0.0000	0.0	0.0	0.0047	15.5	3.9						
Cr	0.0005	0.5	0.3	0.0002	0.7	0.2						
Ni	0.0002	0.2	0.1	0.0000	0.0	0.0						
Mn	0.0007	0.7	0.4	0.0006	2.0	0.5						
Sn	0.0000	0.0	0.0	0.0000	0.0	0.0						
Mo	0.0000	0.0	0.0	0.0000	0.0	0.0						
Ti	0.0018	1.9	0.9	0.0014	4.6	1.2						
Li	0.0000	0.0	0.0	0.0000	0.0	0.0						
Sb	0.0000	0.0	0.0	0.0000	0.0	0.0						
Pb	0.0000	0.0	0.0	0.0002	0.7	0.2						
mg, Metals Found	0.0962	100.0	50.6	0.0304	100.0	25.3						
mg, Filter Loading	0.1900			0.1200								

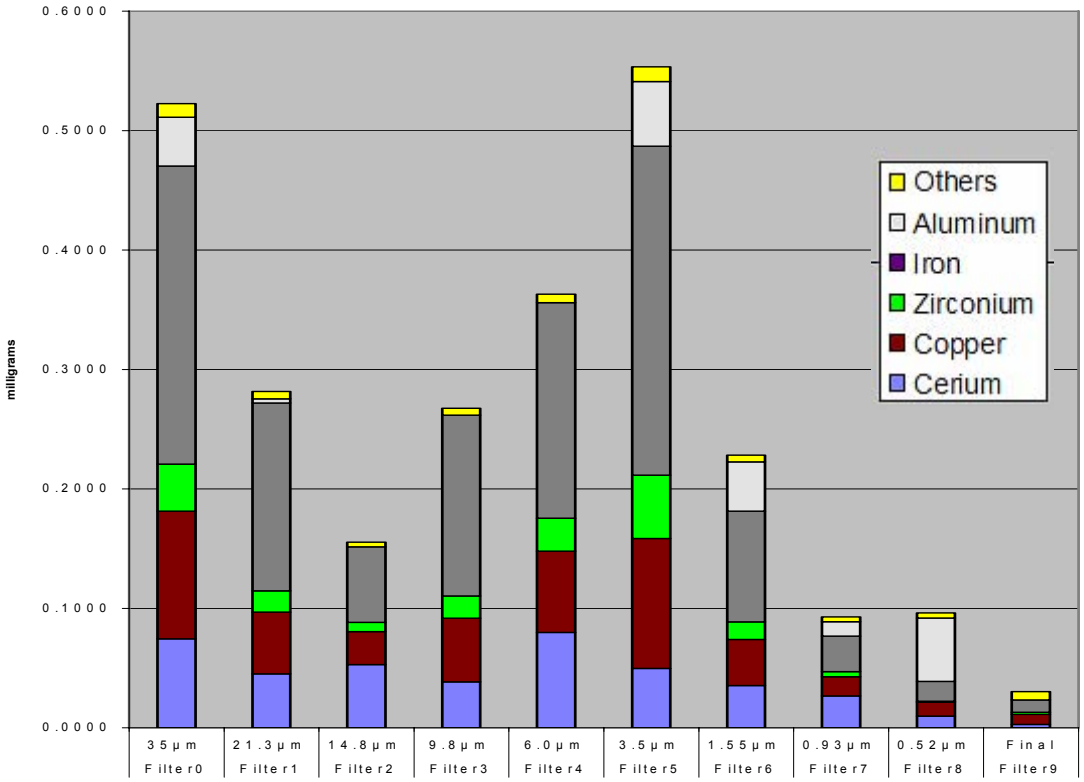


Figure A2.9B.14 Test 2/9B Marple #4 Metals Analysis Distribution, mg

A.2.9C Test 2/9C Gravimetric Results

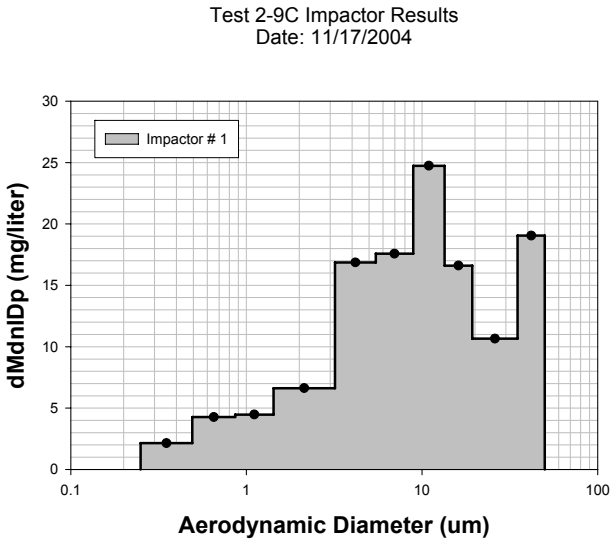


Figure A2.9C.15 Test 2/9C Marple #1 Size Distribution

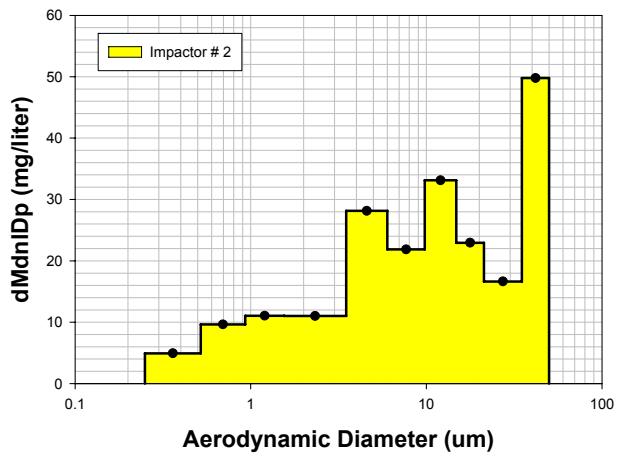


Figure A2.9C.16 Test 2/9C Marple #2 Size Distribution

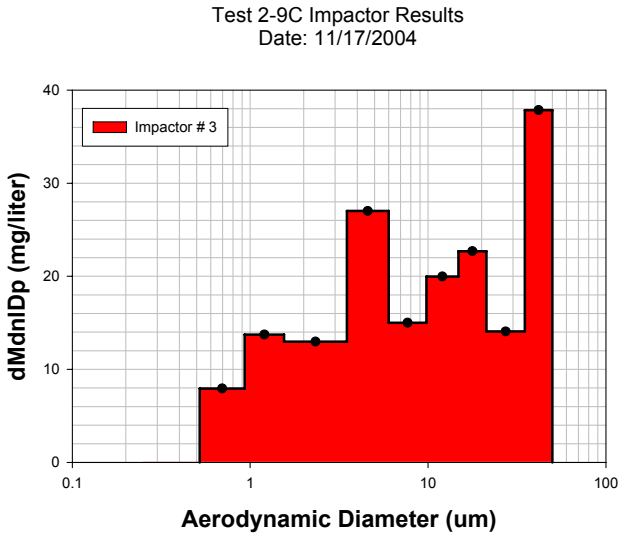


Figure A2.9C.17 Test 2/9C Marple #3 Size Distribution

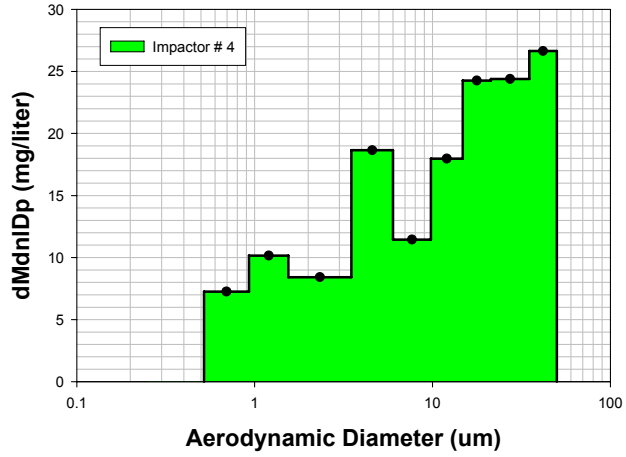


Figure A2.9C.18 Test 2/9C Marple #4 Size Distribution

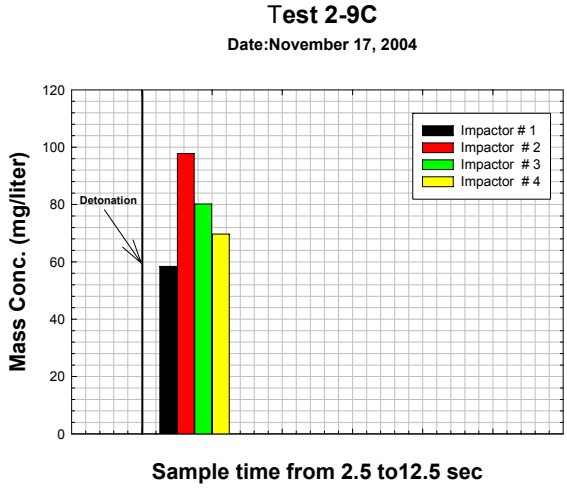


Figure A2.9C.19 Test 2/9C Marple Impactor Mass Concentration Data

A.2.10A Test 2/10A Analyses and Results

For test 2/10A, only particle impact debris collected in the post-test aerosol chamber is available; the control wiring to the aerosol sampling systems (Marple and LPS collectors) were unintentionally disconnected. The weight distribution of the sieved particle impact debris is presented in Table A2.10A.27. Table A2.10A.28 contains the measured impact debris elemental analysis, in weight percent, for the particles from 90 to < 25 µm (geometric) size, or 234 to <65 µm AED for CeO_2 pellets. The weight percent distribution of metals on the impact debris sieved fractions is plotted in Figure A2.10A.20 and Figure A2.10A.21 provides the similar impact debris weight percent distribution of fission product dopants.

Table A2.10A.27 Test 2/10A Weight Distribution of Impact Debris

Sieve #	Opening Size	AED Size for CeO_2	Weight, g Retained	Weight, g Passed	Percent Passed	Percent Retained
18	1.00 mm	2600 µm	18.69	15.58	45.5	54.5
35	500 µm	1300 µm	1.69	13.89	40.5	4.9
60	250 µm	650 µm	2.28	11.62	33.9	6.7
120	125 µm	325 µm	3.2	8.42	24.6	9.3
170	90 µm	234 µm	3.31	5.11	14.9	9.7
200	75 µm	193 µm	0.28	4.83	14.1	0.8
400	38 µm	99 µm	2.81	2.02	5.9	8.2
600	25 µm	65 µm	2.02	0	0	5.9
totals			34.28			100.0

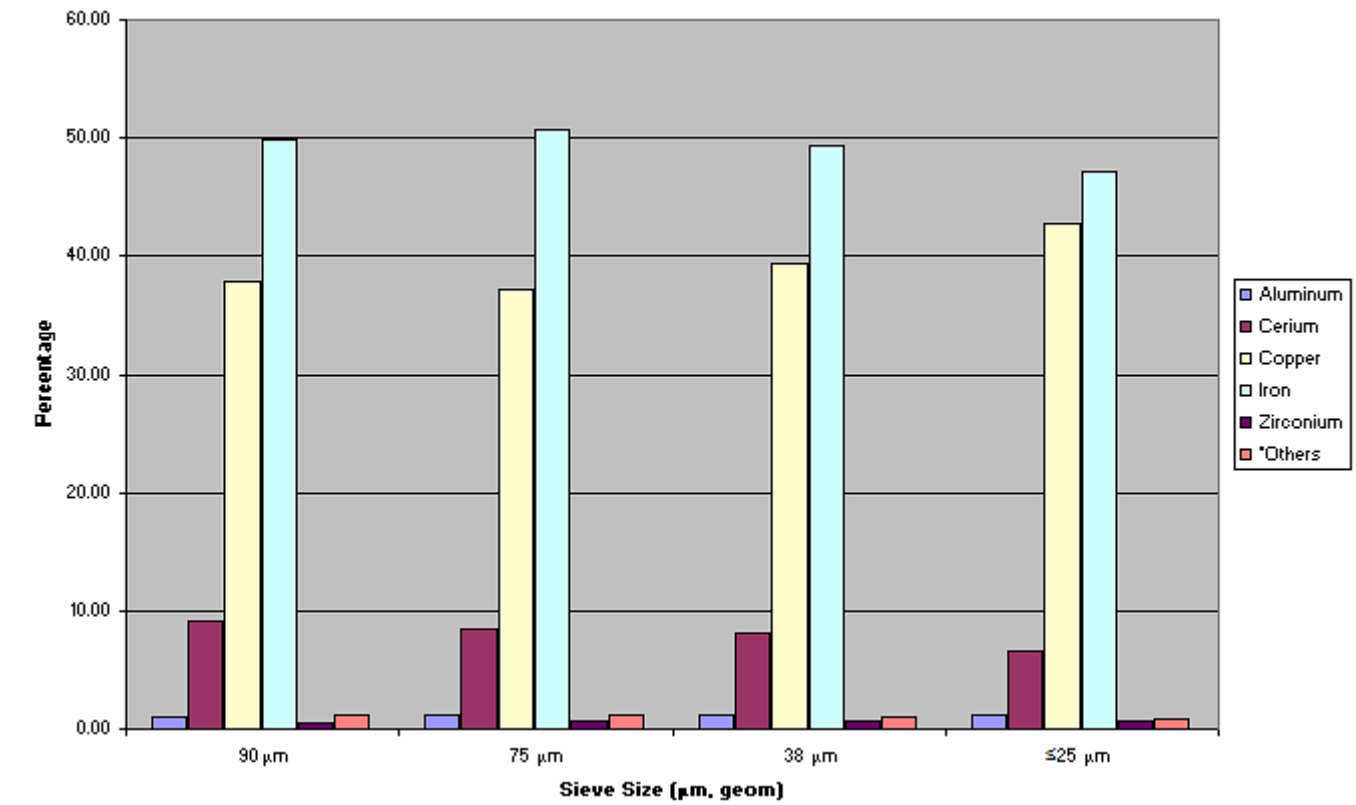


Figure A2.10A.20 Test 2/10A Metals Weight Percent Distribution on Impact Debris Fractions

Table A2.10A.28 Test 2/10A Impact Debris Metals Weight Percent Distribution

Test 2/10A	90 µm	75 µm	38 µm	≤25 µm
Aluminum	1.00	1.21	1.11	1.23
Antimony	0.00	0.00	0.00	0.00
Barium	0.01	0.02	0.01	0.02
Boron	0.00	0.00	0.00	0.00
Cerium	9.20	8.51	8.09	6.64
Cesium	0.10	0.20	0.17	0.33
Chromium	0.05	0.06	0.06	0.06
Copper	37.85	37.26	39.36	42.79
Europium	0.05	0.08	0.06	0.06
Iron	49.92	50.71	49.36	47.11
Lanthanum	0.00	0.00	0.00	0.00
Lead	0.01	0.01	0.01	0.01
Lithium	0.00	0.00	0.00	0.00
Magnesium	0.05	0.07	0.07	0.07
Manganese	0.62	0.62	0.54	0.48
Molybdenum	0.01	0.01	0.01	0.01
Neodymium	0.18	0.14	0.10	0.07
Nickel	0.06	0.05	0.05	0.05
Praseodymium	0.00	0.00	0.00	0.00
Ruthenium	0.07	0.10	0.09	0.11
Samarium	0.00	0.00	0.00	0.00
Strontium	0.09	0.12	0.10	0.13
Terbium	0.00	0.00	0.00	0.00
Titanium	0.14	0.15	0.12	0.12
Zirconium	0.59	0.69	0.68	0.72
*Others	1.13	1.13	0.97	0.88
Totals	100.00	100.00	100.00	100.00

*Sb, Ba, B, Cr, La, Pb, Li, Mg, Mn, Mo, Nd, Ni, Pr, Sm, Tb, Ti,

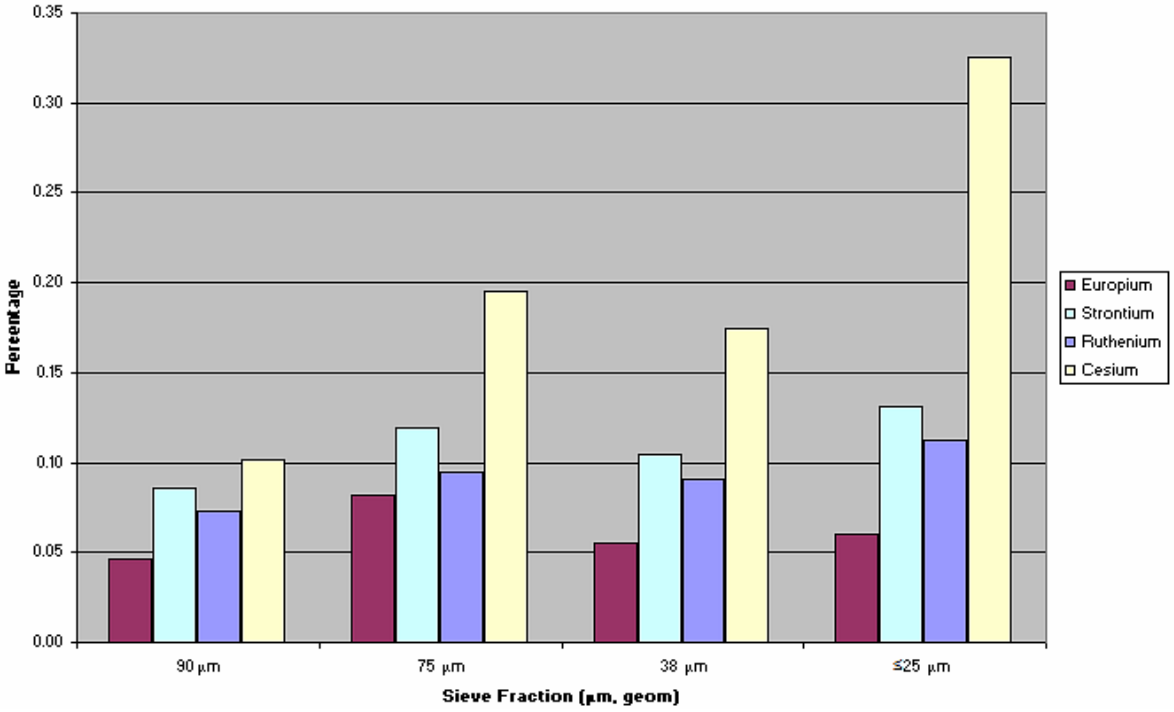


Figure A2.10A.21 Test 2/10A Fission Product Weight Percent Distribution, Impact Debris

A.2.10B Test 2/10B Analyses and Results

Particulates from test 2/10B were sampled using a four independent Large Particle Separator and Marple impactor systems. In addition, multiple separate impact particle debris samples were collected by a HEPA vacuum system and filter socks from various sample points within the aerosol chamber. Deposited particle samples were also obtained from the exterior and interior of each of the four internal chamber sampling tubes. The impact particle debris was also not chemically analyzed since the similar replicate samples from test 2/10A were. Graphs of gravimetric particle size distributions from the four 2/10B Marple impactors, plus the mass concentrations, are presented in Figures A2.10B.22 to Figure A2.10B.26.

Marple and LPS Particle Element Analyses: Chemical analyses were performed on three of the Marple and LPS particle collection systems, the fourth Marple and LPS samples were held in reserve. Each Large Particle Sampler fiberglass substrate was cut into four separate pieces prior to chemical dissolution and elemental analysis by ICP-MS. These LPS segments cover the nominal particle size range of: Segment #1 is ~82-100 μm AED, Segment #2 is ~65-82 μm AED, Segment #3 is ~48-65 μm AED, and Segment #4 is ~30-48 μm AED.

All Marple #1 elemental analyses are listed in Tables A2.10B.29 to A2.10B.31 and are plotted in Figure A2.10B.27 for metals and Figure A2.10B.28 for fission product dopants. All LPS #1 elemental analyses are also listed in Table A2.10B.31 and are plotted in Figure A2.10B.29 for metals and Figure A2.10B.30 for fission product dopants.

All Marple #2 elemental analyses are listed in Tables A2.10B.32 to A2.10B.34 and are plotted in Figure A2.10B.31 for metals and Figure A2.10B.32 for fission product dopants. All LPS #2 elemental analyses are also listed in Table A2.10B.34 and are plotted in Figure A2.10B.33 for metals and Figure A2.10B.34 for fission product dopants.

All Marple #3 elemental analyses are listed in Tables A2.10B.35 to A2.10B.37 and are plotted in Figure A2.10B.35 for metals and Figure A2.10B.36for fission product dopants. All LPS #3 elemental analyses are also listed in Table A2.10B.37 and are plotted in Figure A2.10B.37 for metals and Figure A2.10B.38 for fission product dopants.

NOTE: The final row “mg, Filter Loading” in tables that list the elemental analyses for Marple and LPS samples may be difficult to interpret. This is because the metal elements content for aluminum, barium, magnesium, strontium, and zirconium have not been included. These elements were all present as significant impurities contained within the fiberglass substrates used, and not detected until later. So, the “corrected” values for “mg, Filter Loading” are actually listed as lower in value than the analyzed “mg, metals found.” The primary impact of this high impurity content in the fiberglass substrate is that measured values for “fission product content” for added dopant strontium has been masked. The strontium dopant content values are, therefore, unreliable and are not presented in the figures along with other measured fission product dopants.

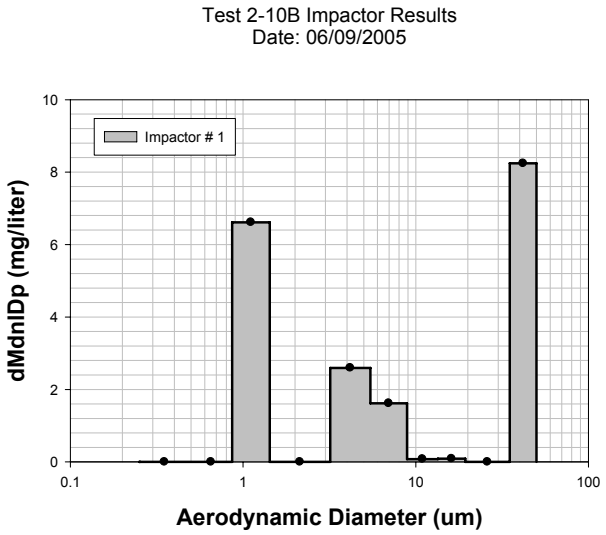


Figure A2.10B.22 Test 2/10B Marple #1 Size Distribution

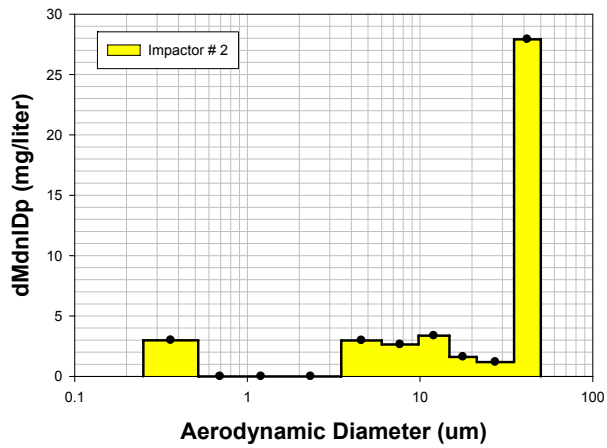


Figure A2.10B.23 Test 2/10B Marple #2 Size Distribution

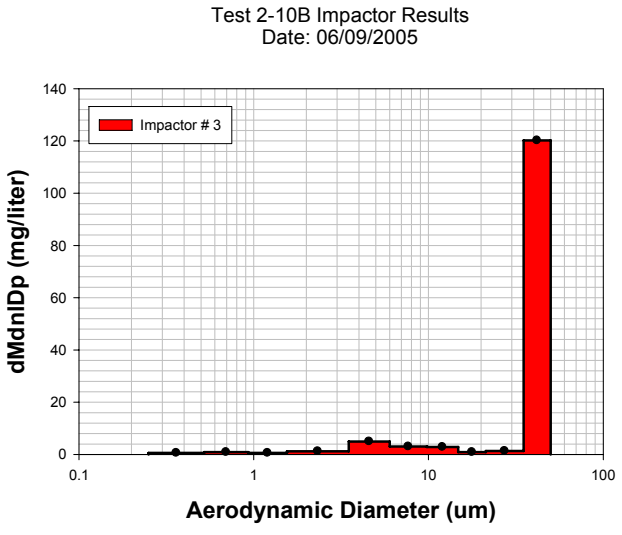


Figure A2.10B.24 Test 2/10B Marple #3 Size Distribution

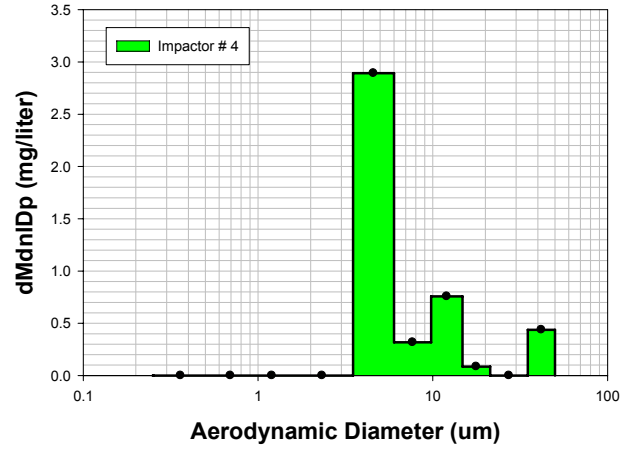


Figure A2.10B.25 Test 2/10B Marple #4 Size Distribution

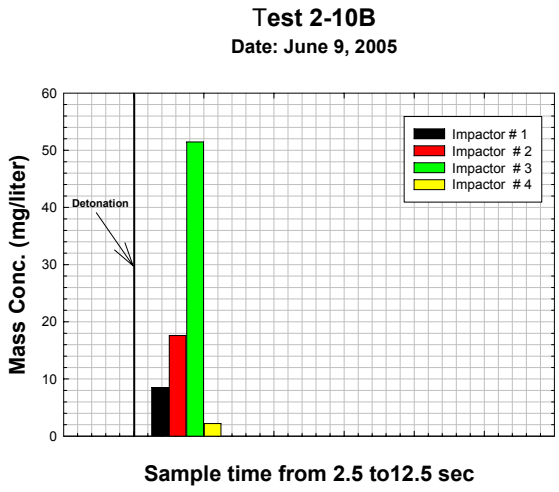


Figure A2.10B.26 Test 2/10B Marple Impactor Mass Concentration Data

Table A2.10B.29 Test 2/10B Marple #1 Elemental Analyses, Stages 0-3

2/10B	STAGE 0			STAGE 1			STAGE 2			STAGE 3		
M #1	Particle size 35 µm			Particle size 21.3 µm			Particle size 14.8 µm			Particle size 9.8 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	2.1100	20.0322		2.0600	19.5947		2.1600	20.7469		2.1200	21.1092	
Antimony	0.0000	0.0004	0.0051	0.0000	0.0004		0.0000	0.0004	0.4000	0.0000	0.0004	0.3900
*Barium	4.7400	45.0013		4.7200	44.8966		4.6700	44.8557		4.4000	43.8115	
*Boron	3.4100	32.3744		3.5100	33.3871		3.3500	32.1770		3.2200	32.0621	
Cerium	0.0028	0.0261	0.3274	0.0013	0.0123		0.0282	0.2709	282.0000	0.0693	0.6900	693.0000
Cesium	0.0034	0.0322	0.4036	0.0016	0.0148		0.0007	0.0071	7.4100	0.0009	0.0086	8.6100
Chromium	0.0011	0.0103	0.1286	0.0010	0.0096		0.0009	0.0089	9.3100	0.0009	0.0093	9.2900
Copper	0.0381	0.3617	4.5357	0.0174	0.1655		0.0110	0.1057	110.0000	0.0193	0.1922	193.0000
Europium	0.0009	0.0084	0.1057	0.0008	0.0074		0.0008	0.0076	7.9200	0.0008	0.0083	8.3200
Iron	0.0659	0.6257	7.8452	0.0459	0.4366		0.0413	0.3967	413.0000	0.0538	0.5357	538.0000
La	0.0002	0.0015	0.0186	0.0001	0.0014		0.0001	0.0014	1.4700	0.0002	0.0015	1.5200
Lead	0.0010	0.0099	0.1238	0.0010	0.0095		0.0010	0.0095	9.9000	0.0010	0.0102	10.2000
Lithium	0.0007	0.0864	0.0864	0.0007	0.0066		0.0006	6.4300		0.0007	6.5300	
*Mg	0.1280	1.2152		0.1250	1.1890		0.1170	1.1238		0.1230	1.2247	
Mn	0.0017	0.0160	0.2012	0.0014	0.0136		0.0014	0.0133	13.8000	0.0015	0.0150	15.1000
Mo	0.0005	0.0049	0.0611	0.0002	0.0023		0.0001	0.0012	1.3000	0.0002	0.0016	1.6500
Nd	0.0002	0.0023	0.0292	0.0002	0.0015		0.0007	0.0064	6.6600	0.0014	0.0142	14.3000
Nickel	0.0003	0.0024	0.0299	0.0002	0.0021		0.0002	0.0019	1.9700	0.0002	0.0018	1.8300
Pr	0.0000	0.0004	0.0044	0.0000	0.0003		0.0000	0.0003	0.3500	0.0000	0.0004	0.3700
Ruthenium	0.0004	0.0040	0.0502	0.0002	0.0017		0.0001	0.0010	1.0800	0.0002	0.0018	1.8200
Samarium	0.0012	0.0109	0.1369	0.0011	0.0106		0.0011	0.0106	11.0000	0.0011	0.0110	11.0000
*Strontium	0.0161	0.1529		0.0160	0.1522		0.0162	0.1556		0.0166	0.1653	
Terbium	0.0000	0.0001	0.0014	0.0000	0.0001		0.0000	0.0001	0.1400	0.0000	0.0002	0.1800
Titanium	0.0016	0.0148	0.1857	0.0014	0.0137		0.0015	0.0146	15.2000	0.0017	0.0170	17.1000
*Zirconium	0.0090	0.0852		0.0074	0.0703		0.0080	0.0772		0.0102	0.1016	
Others	0.2232			0.1970			0.1839	1.7667		0.2042		
mg, Metals Found	10.5330	100.0795	14.2801	10.5130	100.0000	0.0000	10.4112	106.4238	892.9100	10.0430	106.5235	1525.6800
mg, Filter Loading	0.8400			0.0000			0.0100			0.0100		

*High Al, Ba, B, Mg, Europium (?), Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti, Zr

Table A2.10B.30 Test 2/10B Marple #1 Elemental Analyses, Stages 4-7

2/10B	STAGE 4			STAGE 5			STAGE 6			STAGE 7		
M #1	Particle size 6.0 µm			Particle size 3.5 µm			Particle size 1.55 µm			Particle size 0.93 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	2.1600	19.2968		2.1800	20.3363		2.2500	21.3155		2.0300	19.4720	
Antimony	0.0000	0.0004	0.0160	0.0000	0.0004	0.0098	0.0000	0.0004		0.0000	0.0004	0.0041
*Barium	5.0400	45.0258		4.7000	43.8442		4.5600	43.1995		4.6100	44.2196	
*Boron	3.6800	32.8760		3.5300	32.9298		3.4900	33.0628		3.5900	34.4357	
Cerium	0.0614	0.5485	24.5600	0.0038	0.0350	0.8523	0.0022	0.0209		0.0008	0.0073	0.0723
Cesium	0.0012	0.0105	0.4680	0.0042	0.0396	0.9636	0.0040	0.0376		0.0012	0.0110	0.1095
Chromium	0.0010	0.0088	0.3932	0.0011	0.0099	0.2409	0.0010	0.0092		0.0009	0.0082	0.0816
Copper	0.0228	0.2037	9.1200	0.0528	0.4925	12.0000	0.0385	0.3647		0.0087	0.0832	0.8257
Europium	0.0009	0.0079	0.3532	0.0010	0.0089	0.2159	0.0008	0.0078		0.0007	0.0071	0.0701
Iron	0.0602	0.5378	24.0800	0.0854	0.7967	19.4091	0.0514	0.4869		0.0345	0.3309	3.2857
La	0.0002	0.0014	0.0644	0.0002	0.0015	0.0364	0.0002	0.0015		0.0001	0.0014	0.0142
Lead	0.0011	0.0094	0.4200	0.0011	0.0101	0.2455	0.0010	0.0098		0.0010	0.0096	0.0950
Lithium	0.0007	0.2628		0.0006	0.1466		0.0006	0.0060		0.0006	0.0594	
*Mg	0.1310	1.1703		0.1270	1.1847		0.1250	1.1842		0.1190	1.1415	
Mn	0.0016	0.0140	0.6280	0.0018	0.0170	0.4136	0.0015	0.0144		0.0013	0.0126	0.1248
Mo	0.0002	0.0018	0.0804	0.0006	0.0056	0.1370	0.0006	0.0053		0.0002	0.0016	0.0161
Nd	0.0011	0.0100	0.4480	0.0002	0.0017	0.0420	0.0003	0.0030		0.0001	0.0013	0.0125
Nickel	0.0002	0.0017	0.0768	0.0002	0.0022	0.0545	0.0002	0.0016		0.0001	0.0014	0.0142
Pr	0.0000	0.0003	0.0156	0.0000	0.0003	0.0082	0.0000	0.0003		0.0000	0.0003	0.0032
Ruthenium	0.0002	0.0022	0.0976	0.0007	0.0064	0.1561	0.0004	0.0039		0.0001	0.0009	0.0090
Samarium	0.0011	0.0101	0.4520	0.0011	0.0103	0.2500	0.0011	0.0104		0.0010	0.0100	0.0990
*Strontium	0.0168	0.1501		0.0171	0.1595		0.0169	0.1601		0.0165	0.1583	
Terbium	0.0000	0.0002	0.0072	0.0000	0.0001	0.0025	0.0000	0.0001		0.0000	0.0001	0.0010
Titanium	0.0017	0.0155	0.6920	0.0017	0.0158	0.3841	0.0016	0.0148		0.0014	0.0137	0.1362
*Zirconium	0.0102	0.0911		0.0092	0.0855		0.0084	0.0793		0.0069	0.0660	
Others	0.2192			0.2441			0.2066			0.1789		
mg, Metals Found	11.1936	100.2569	61.9724	10.7198	100.1406	35.4216	10.5557	100.0000	0.0000	10.4252	100.0534	4.9743
mg, Filter Loading	0.2500			0.4400			0.0000			1.0500		

*High Al, Ba, B, Mg, Europium (?), Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti, Zr

Table A2.10B.31 Test 2/10B Marple #1 Elemental Analyses, Stages 8-9 & LPS #1

2/10B	STAGE 8			STAGE 9				LPS #1			
M #1	Particle size 0.52 µm			Particle size final, <0.5 µm				S1: ~82-100 µm	S2: ~65-82 µm	S3: ~48-65 µm	S4: ~30-48 µm
	mg	% detect	% loading	mg	% detect	% loading		mg	mg	mg	mg
*Aluminum	2.0600	20.1752		2.6200	22.1014			1.9400	2.0400	1.9000	2.0300
Antimony	0.0000	0.0004		0.0001	0.0005			0.0000	0.0000	0.0000	0.0001
*Barium	4.4800	43.8761		5.1100	43.1061			4.0000	4.0800	3.7600	4.0900
*Boron	3.4500	33.7885		3.8500	32.4772			3.0000	2.9200	2.9200	3.2000
Cerium	0.0056	0.0548		0.0060	0.0502			0.0006	0.0004	0.0003	0.0017
Cesium	0.0033	0.0319		0.0055	0.0462			0.0001	0.0000	0.0000	0.0000
Chromium	0.0009	0.0086		0.0013	0.0110			0.0018	0.0019	0.0023	0.0035
Copper	0.0209	0.2047		0.0330	0.2784			0.0033	0.0016	0.0011	0.0036
Europium	0.0008	0.0076		0.0008	0.0070			0.0006	0.0006	0.0006	0.0006
Iron	0.0360	0.3526		0.0455	0.3838			0.0357	0.0338	0.0338	0.0395
La	0.0002	0.0015		0.0002	0.0017			0.0001	0.0001	0.0001	0.0002
Lead	0.0010	0.0099		0.0012	0.0102			0.0010	0.0010	0.0010	0.0010
Lithium	0.0006	0.0063		0.0007	0.0062			0.0005	0.0005	0.0005	0.0006
*Mg	0.1200	1.1753		0.1430	1.2063			0.1090	0.1100	0.1080	0.1110
Mn	0.0014	0.0132		0.0016	0.0135			0.0012	0.0012	0.0012	0.0013
Mo	0.0005	0.0048		0.0009	0.0079			0.0000	0.0000	0.0001	0.0001
Nd	0.0002	0.0023		0.0004	0.0030			0.0001	0.0001	0.0001	0.0002
Nickel	0.0001	0.0015		0.0003	0.0021			0.0007	0.0008	0.0011	0.0017
Pr	0.0000	0.0003		0.0000	0.0004			0.0000	0.0000	0.0000	0.0000
Ruthenium	0.0002	0.0023		0.0004	0.0030			0.0000	0.0000	0.0000	0.0000
Samarium	0.0011	0.0106		0.0012	0.0100			0.0009	0.0009	0.0009	0.0009
*Strontium	0.0166	0.1626		0.0182	0.1535			0.0148	0.0151	0.0143	0.0149
Terbium	0.0000	0.0001		0.0000	0.0001			0.0000	0.0000	0.0000	0.0000
Titanium	0.0016	0.0161		0.0017	0.0139			0.0014	0.0015	0.0013	0.0015
*Zirconium	0.0095	0.0929		0.0126	0.1063			0.0071	0.0072	0.0066	0.0073
Others	0.1846			0.2229				0.1682	0.1678	0.1655	0.1770
mg, Metals Found	10.2106	100.0000	0.0000	11.8545	100.0000	0.0000		9.1192	9.2169	8.7535	9.5095
mg, Filter Loading	0.0000			0.0000							

*High Al, Ba, B, Mg, Europium (?), Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti, Zr

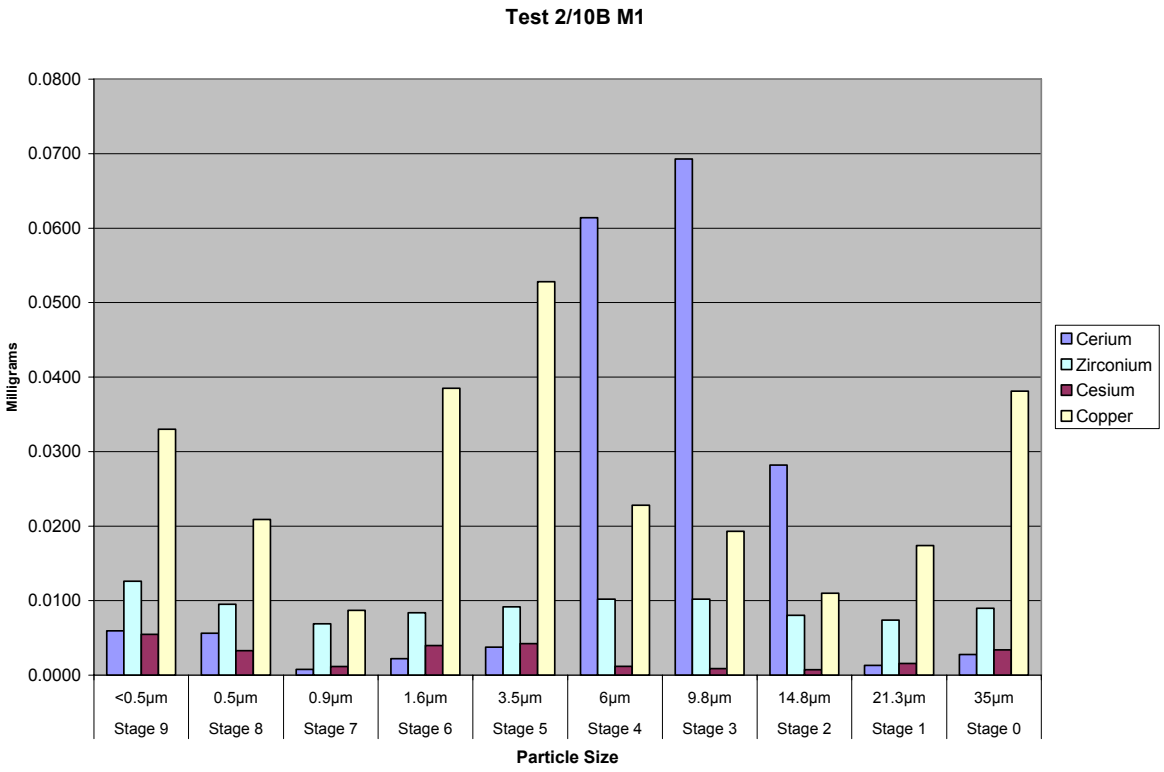


Figure A2.10B.27 Test 2/10B Marple #1 Metals Analysis Distribution, mg

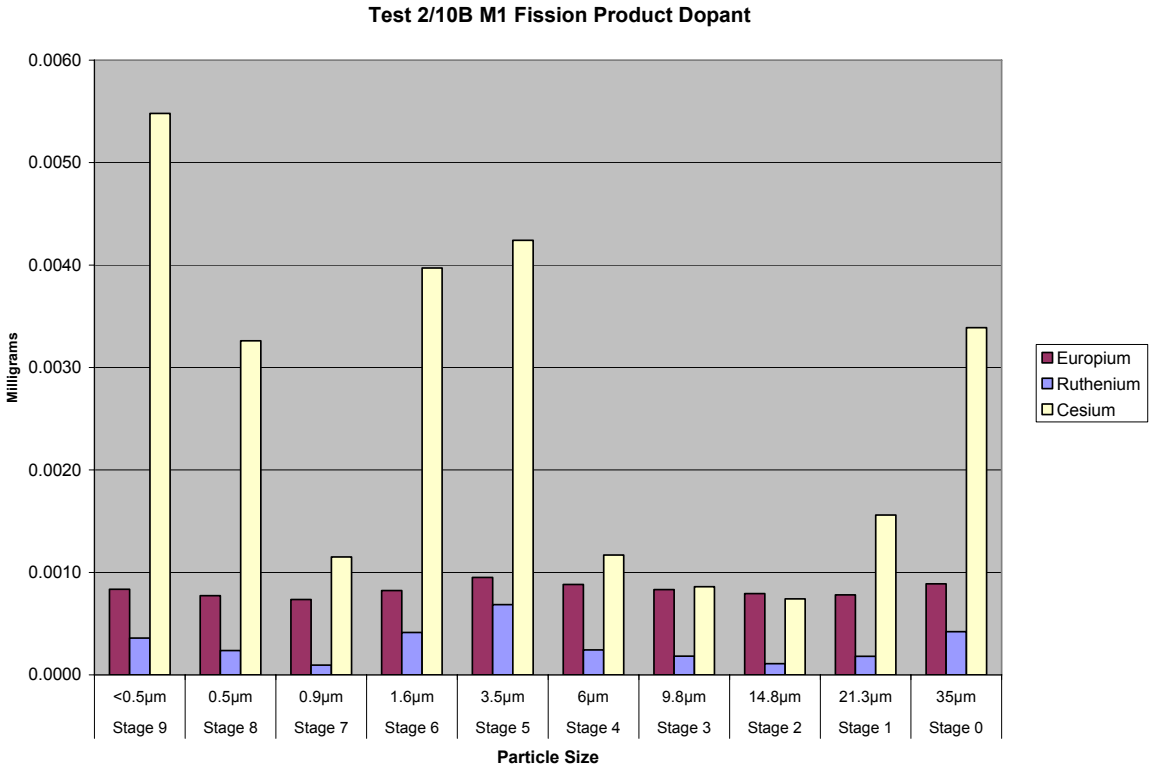


Figure A2.10B.28 Test 2/10B Marple #1 Fission Product Dopant Distribution, mg

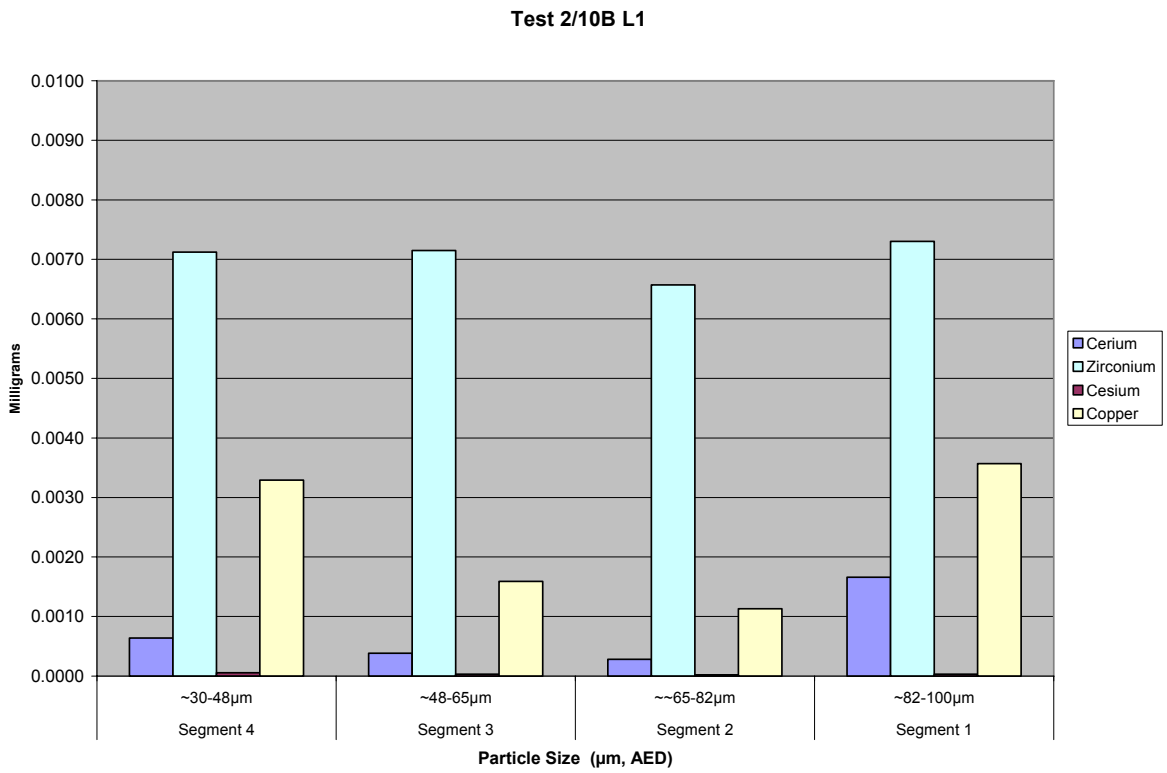


Figure A2.10B.29 Test 2/10B LPS #1 Metals Analysis Distribution, mg

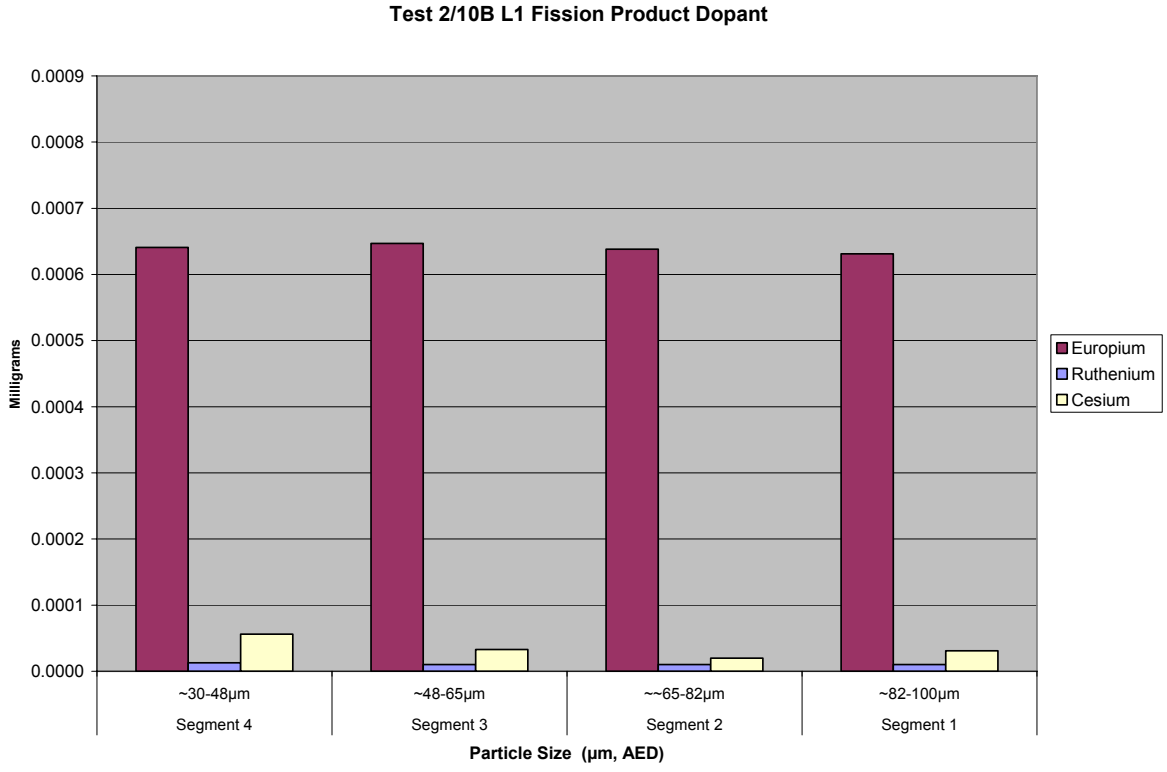


Figure A2.10B.30 Test 2/10B LPS #1 Fission Product Dopant Distribution, mg

Table A2.10B.32 Test 2/10B Marple #2 Elemental Analyses, Stages 0-3

2/10B	STAGE 0			STAGE 1			STAGE 2			STAGE 3		
M #2	Particle size 35 µm			Particle size 21.3 µm			Particle size 14.8 µm			Particle size 9.8 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	2.1800	20.7336		2.2500	20.8195		2.3500	21.9375		2.3800	20.5474	
Antimony	0.0000	0.0004	0.0012	0.0001	0.0005	0.0015	0.0000	0.0004	0.0221	0.0001	0.0005	0.0118
*Barium	4.6000	43.7498		4.7500	43.9522		4.5700	42.6614		5.0100	43.2532	
*Boron	3.3300	31.6711		3.5200	32.5709		3.5300	32.9529		3.8000	32.8068	
Cerium	0.0987	0.9387	3.0557	0.0444	0.4108	1.3746	0.0279	0.2604	14.6842	0.1020	0.8806	22.6667
Cesium	0.0053	0.0499	0.1625	0.0023	0.0213	0.0712	0.0009	0.0088	0.4963	0.0017	0.0150	0.3867
Chromium	0.0016	0.0154	0.0502	0.0012	0.0108	0.0362	0.0012	0.0112	0.6316	0.0010	0.0087	0.2244
Copper	0.0551	0.5240	1.7059	0.0255	0.2360	0.7895	0.0151	0.1410	7.9474	0.0374	0.3229	8.3111
Europium	0.0009	0.0088	0.0285	0.0009	0.0079	0.0264	0.0008	0.0073	0.4111	0.0010	0.0084	0.2167
Iron	0.0825	0.7846	2.5542	0.0559	0.5172	1.7307	0.0491	0.4584	25.8421	0.0822	0.7097	18.2667
La	0.0002	0.0015	0.0048	0.0002	0.0015	0.0050	0.0002	0.0015	0.0858	0.0002	0.0015	0.0380
Lead	0.0010	0.0098	0.0319	0.0011	0.0097	0.0325	0.0010	0.0093	0.5221	0.0011	0.0095	0.2444
Lithium	0.0006	0.0058	0.0190	0.0006	0.0058	0.0195	0.0006	0.0058	0.3274	0.0006	0.0055	0.1422
*Mg	0.1190	1.1318		0.1290	1.1936		0.1360	1.2696		0.1350	1.1655	
Mn	0.0018	0.0172	0.0560	0.0016	0.0145	0.0486	0.0014	0.0133	0.7474	0.0018	0.0159	0.4089
Mo	0.0009	0.0083	0.0269	0.0004	0.0035	0.0118	0.0002	0.0018	0.1005	0.0003	0.0026	0.0669
Nd	0.0019	0.0177	0.0576	0.0008	0.0077	0.0258	0.0007	0.0065	0.3653	0.0020	0.0174	0.4489
Nickel	0.0006	0.0053	0.0174	0.0004	0.0037	0.0125	0.0002	0.0017	0.0947	0.0002	0.0020	0.0511
Pr	0.0000	0.0004	0.0012	0.0000	0.0004	0.0012	0.0000	0.0004	0.0205	0.0000	0.0004	0.0093
Ruthenium	0.0006	0.0059	0.0191	0.0003	0.0025	0.0085	0.0001	0.0014	0.0774	0.0004	0.0034	0.0873
Samarium	0.0010	0.0099	0.0322	0.0011	0.0104	0.0347	0.0010	0.0096	0.5421	0.0012	0.0101	0.2600
*Strontium	0.0169	0.1607		0.0176	0.1629		0.0171	0.1596		0.0184	0.1589	
Terbium	0.0000	0.0002	0.0007	0.0000	0.0001	0.0005	0.0000	0.0001	0.0074	0.0000	0.0002	0.0051
Titanium	0.0019	0.0179	0.0582	0.0017	0.0155	0.0520	0.0012	0.0115	0.6474	0.0017	0.0149	0.3844
*Zirconium	0.0138	0.1312		0.0023	0.0210		0.0074	0.0688		0.0045	0.0391	
Others												
mg, Metals Found	10.5143	100.0000	7.8832	10.8072	100.0000	4.2826	10.7123	100.0000	53.5726	11.5830	100.0000	52.2307
mg, Filter Loading	3.2300			3.2300			0.1900			0.4500		

*High Al, Ba, B, Mg, Europium (?), Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti, Zr

Table A2.10B.33 Test 2/10B Marple #2 Elemental Analyses, Stages 4-7

2/10B	STAGE 4			STAGE 5			STAGE 6			STAGE 7		
M #2	Particle size 6.0 µm			Particle size 3.5 µm			Particle size 1.55 µm			Particle size 0.93 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	2.2300	20.1044		2.21000	20.73695		2.3600	22.9231		2.1900	20.7925	
Antimony	0.0000	0.0004	0.0093	0.00005	0.00043	0.0088	0.0001	0.0005		0.0000	0.0004	
*Barium	4.8100	43.3642		4.48000	42.03689		4.4100	42.8352		4.6400	44.0536	
*Boron	3.6600	32.9965		3.55000	33.31048		3.2500	31.5679		3.4400	32.6604	
Cerium	0.0972	0.8763	21.6000	0.08870	0.83229	17.0577	0.0296	0.2875		0.0149	0.1415	
Cesium	0.0022	0.0197	0.4844	0.00525	0.04926	1.0096	0.0040	0.0385		0.0053	0.0503	
Chromium	0.0010	0.0089	0.2184	0.00102	0.00957	0.1962	0.0011	0.0104		0.0009	0.0085	
Copper	0.0374	0.3372	8.3111	0.06050	0.56769	11.6346	0.0319	0.3099		0.0370	0.3513	
Europium	0.0010	0.0088	0.2173	0.00103	0.00966	0.1981	0.0010	0.0094		0.0009	0.0083	
Iron	0.0787	0.7095	17.4889	0.09360	0.87827	18.0000	0.0538	0.5226		0.0440	0.4177	
La	0.0002	0.0015	0.0362	0.00015	0.00144	0.0294	0.0002	0.0017		0.0002	0.0016	
Lead	0.0011	0.0097	0.2400	0.00099	0.00929	0.1904	0.0010	0.0100		0.0010	0.0097	
Lithium	0.0006	0.0059	0.1442	0.00062	0.00582	0.1192	0.0006	0.0057		0.0006	0.0054	
*Mg	0.1350	1.2171		0.12800	1.20105		0.1260	1.2239		0.1230	1.1678	
Mn	0.0018	0.0159	0.3911	0.00189	0.01773	0.3635	0.0015	0.0146		0.0015	0.0138	
Mo	0.0003	0.0030	0.0742	0.00070	0.00660	0.1352	0.0006	0.0054		0.0008	0.0077	
Nd	0.0019	0.0167	0.4111	0.00154	0.01445	0.2962	0.0004	0.0036		0.0002	0.0021	
Nickel	0.0002	0.0018	0.0440	0.00022	0.00204	0.0417	0.0002	0.0018		0.0002	0.0016	
Pr	0.0000	0.0004	0.0089	0.00004	0.00036	0.0073	0.0000	0.0004		0.0000	0.0003	
Ruthenium	0.0004	0.0039	0.0964	0.00081	0.00758	0.1554	0.0005	0.0044		0.0005	0.0044	
Samarium	0.0011	0.0103	0.2533	0.00106	0.00995	0.2038	0.0013	0.0121		0.0012	0.0109	
*Strontium	0.0183	0.1650		0.01740	0.16327		0.0173	0.1680		0.0173	0.1643	
Terbium	0.0000	0.0002	0.0049	0.00002	0.00020	0.0040	0.0000	0.0002		0.0000	0.0001	
Titanium	0.0017	0.0157	0.3867	0.00152	0.01426	0.2923	0.0018	0.0176		0.0018	0.0167	
*Zirconium	0.0119	0.1073		0.01220	0.11448		0.0027	0.0257		0.0115	0.1092	
Others												
mg, Metals Found	11.0921	100.0000	50.4207	10.6573	100.0000	49.9435	10.2953	100.0000	0.0000	10.5326	100.0000	0.0000
mg, Filter Loading	0.4200			0.5200			0.0000			0.0000		

*High Al, Ba, B, Mg, Europium (?), Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti, Zr

Table A2.10B.34 Test 2/10B Marple #2 Elemental Analyses, Stages 8-9 & LPS #2

2/10B	STAGE 8			STAGE 9				LPS #2			
M #2	Particle size 0.52 µm			Particle size final, <0.5 µm				S1: ~82-100 µm	S2: ~65-82 µm	S3: ~48-65 µm	S4: ~30-48 µm
	mg	% detect	% loading	mg	% detect	% loading		mg	mg	mg	mg
*Aluminum	2.3300	21.4362		2.4000	20.9555			2.0500	1.9600	2.0000	1.8800
Antimony	0.0000	0.0003		0.0001	0.0004	0.0070		0.0000	0.0000	0.0000	0.0000
*Barium	4.7300	43.5164		5.1100	44.6177			4.1300	3.8500	3.7700	3.7600
*Boron	3.5700	32.8443		3.6800	32.1317			2.9900	2.8600	2.8700	2.8400
Cerium	0.0062	0.0568		0.0029	0.0256	0.4127		0.0004	0.0003	0.0106	0.0101
Cesium	0.0049	0.0451		0.0050	0.0436	0.7028		0.0001	0.0001	0.0001	0.0001
Chromium	0.0009	0.0087		0.0009	0.0083	0.1335		0.0011	0.0011	0.0014	0.0018
Copper	0.0278	0.2558		0.0306	0.2672	4.3099		0.0022	0.0017	0.0039	0.0059
Europium	0.0009	0.0081		0.0010	0.0084	0.1351		0.0008	0.0007	0.0007	0.0007
Iron	0.0375	0.3450		0.0399	0.3484	5.6197		0.0303	0.0301	0.0345	0.0396
La	0.0002	0.0017		0.0002	0.0018	0.0289		0.0002	0.0002	0.0002	0.0002
Lead	0.0011	0.0099		0.0013	0.0115	0.1859		0.0010	0.0010	0.0010	0.0010
Lithium	0.0006	0.0056		0.0006	0.0054	0.0866		0.0005	0.0005	0.0005	0.0005
*Mg	0.1230	1.1316		0.1430	1.2486			0.1130	0.1100	0.1100	0.1040
Mn	0.0014	0.0127		0.0015	0.0128	0.2070		0.0011	0.0011	0.0011	0.0013
Mo	0.0007	0.0068		0.0009	0.0077	0.1239		0.0000	0.0000	0.0001	0.0002
Nd	0.0003	0.0025		0.0002	0.0021	0.0335		0.0002	0.0002	0.0003	0.0003
Nickel	0.0002	0.0014		0.0001	0.0012	0.0187		0.0003	0.0003	0.0005	0.0010
Pr	0.0000	0.0004		0.0000	0.0004	0.0063		0.0000	0.0000	0.0000	0.0000
Ruthenium	0.0003	0.0028		0.0003	0.0030	0.0476		0.0000	0.0000	0.0000	0.0000
Samarium	0.0013	0.0116		0.0014	0.0122	0.1972		0.0011	0.0011	0.0010	0.0010
*Strontium	0.0183	0.1684		0.0187	0.1633			0.0161	0.0152	0.0152	0.0147
Terbium	0.0000	0.0001		0.0000	0.0001	0.0020		0.0000	0.0000	0.0000	0.0000
Titanium	0.0020	0.0185		0.0018	0.0159	0.2563		0.0016	0.0015	0.0014	0.0015
*Zirconium	0.0119	0.1095		0.0123	0.1074			0.0078	0.0073	0.0066	0.0069
Others											
mg, Metals Found	10.8695	100.0000	0.0000	11.4529	100.0000	12.5148		9.3478	8.8423	8.8292	8.6706
mg, Filter Loading	0.0000			0.7100							

*High Al, Ba, B, Mg, Europium, Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti, Zr

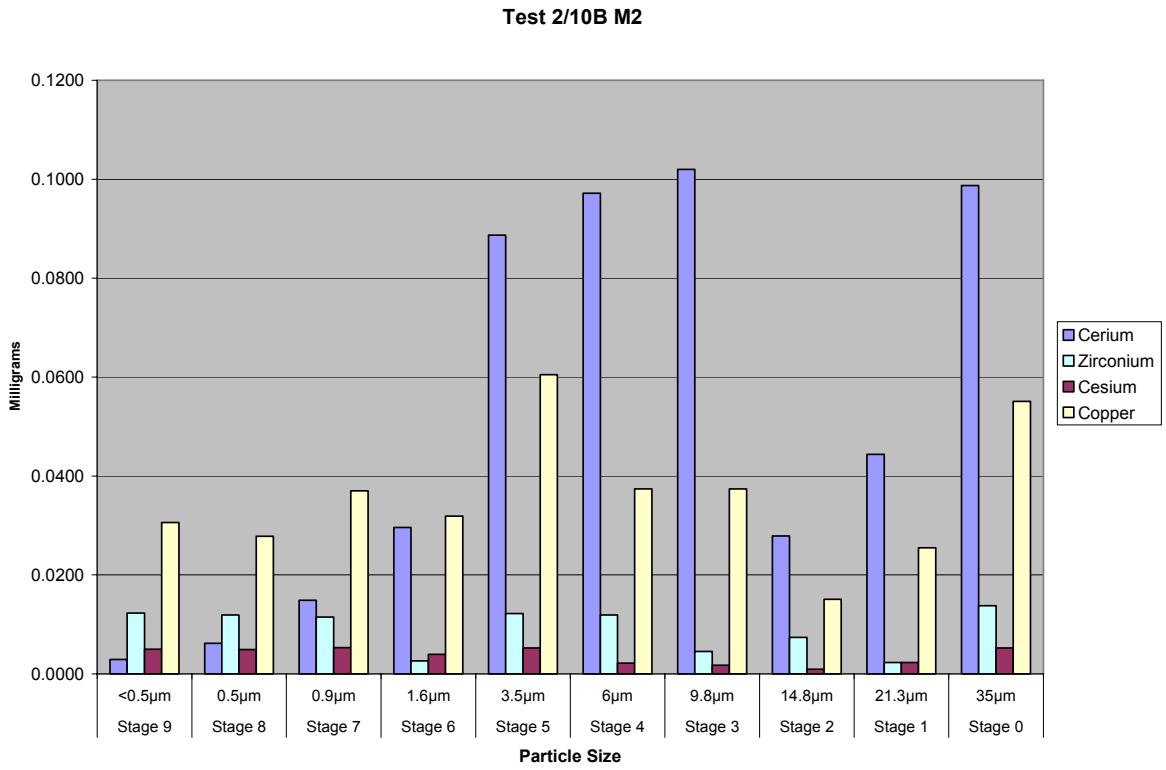


Figure A2.10B.31 Test 2/10B Marple #2 Metals Analysis Distribution, mg

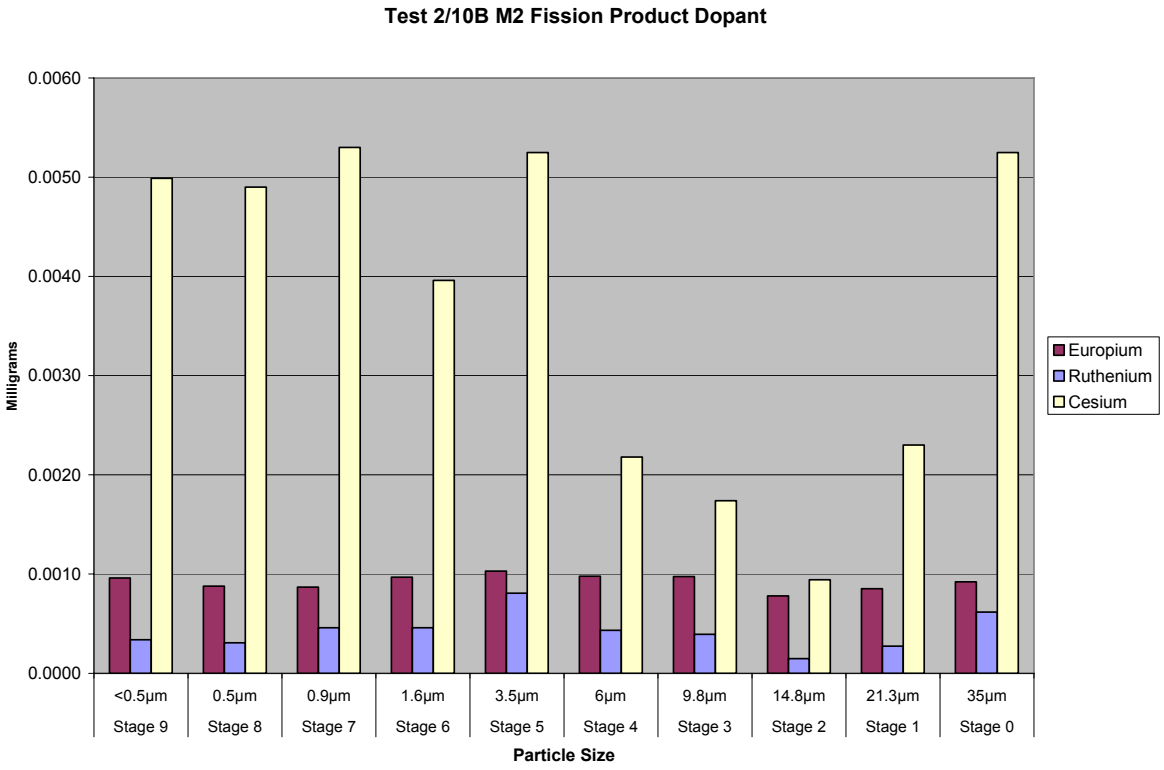


Figure A2.10B.32 Test 2/10B Marple #2 Fission Product Dopant Distribution, mg

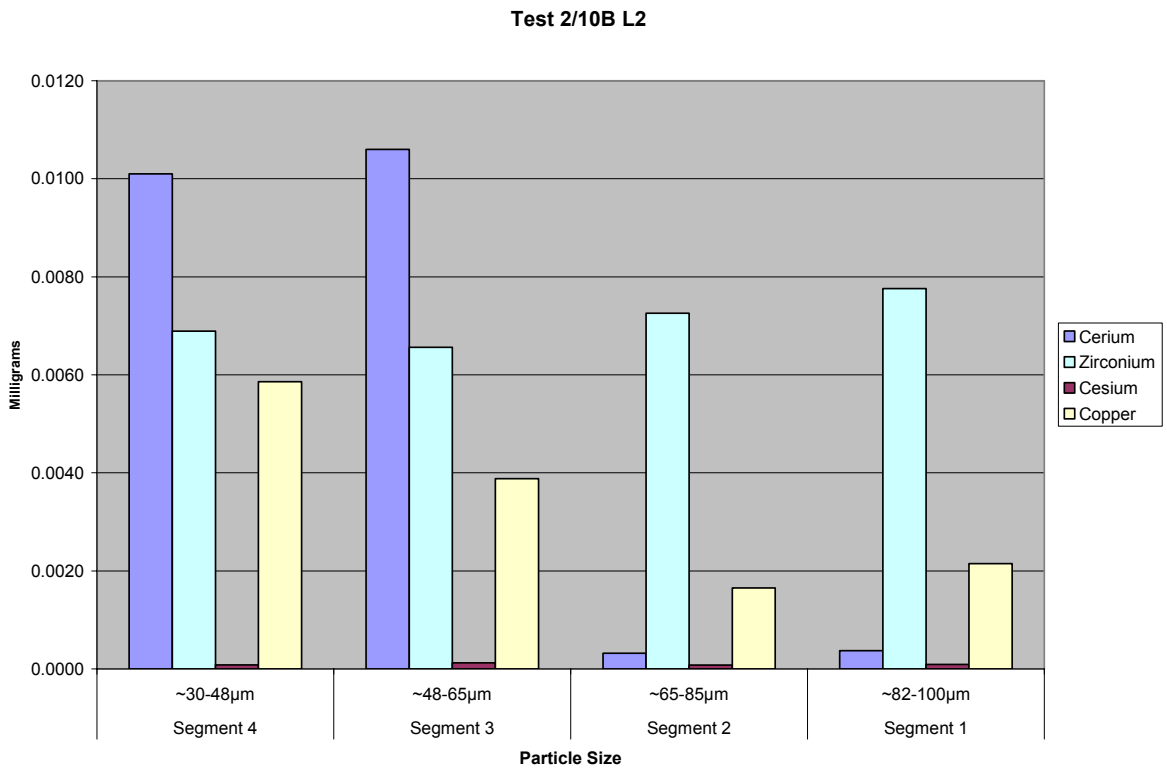


Figure A2.10B.33 Test 2/10B LPS #2 Metals Analysis Distribution, mg

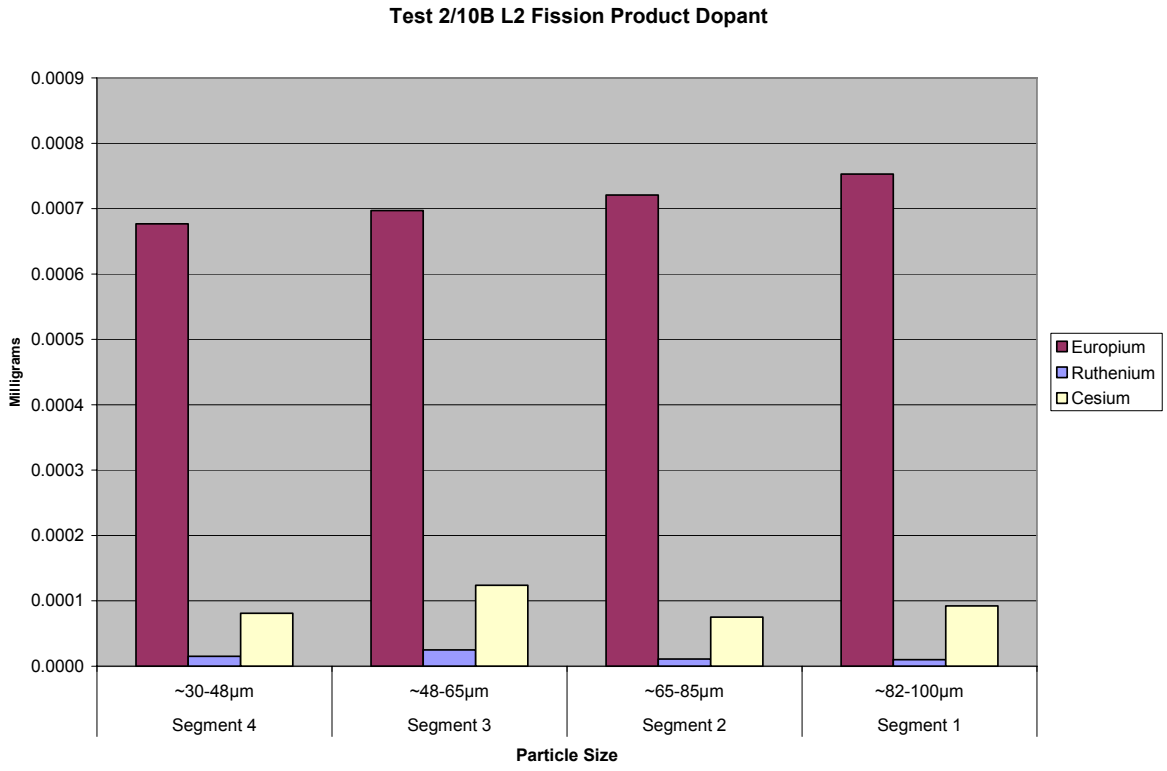


Figure A2.10B.34 Test 2/10B LPS #2 Fission Product Dopant Distribution, mg

Table A2.10B.35 Test 2/10B Marple #3 Elemental Analyses, Stages 0-3

2/10B	STAGE 0			STAGE 1			STAGE 2			STAGE 3		
M #3	Particle size 35 µm			Particle size 21.3 µm			Particle size 14.8 µm			Particle size 9.8 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	2.3400	21.8525		2.3100	21.7458		2.2200	20.9531		11.4000	56.9620	
Antimony	0.0000	0.0004	0.0003	0.0000	0.0004	0.0003	0.0000	0.0004	0.0373	0.0002	0.0009	0.0485
*Barium	4.5400	42.3976		4.6700	43.9623		4.7300	44.6434		4.4700	22.3351	
*Boron	3.4800	32.4986		3.4200	32.1951		3.4100	32.1848		3.3100	16.5390	
Cerium	0.0666	0.6220	0.4861	0.0015	0.0141	0.0106	0.0275	0.2596	25.0000	0.1010	0.5047	25.8974
Cesium	0.0046	0.0427	0.0334	0.0017	0.0155	0.0117	0.0009	0.0088	0.8473	0.0016	0.0079	0.4077
Chromium	0.0010	0.0091	0.0071	0.0009	0.0087	0.0066	0.0009	0.0081	0.7791	0.0046	0.0229	1.1769
Copper	0.0431	0.4025	0.3146	0.0160	0.1506	0.1133	0.0114	0.1076	10.3636	0.1510	0.7545	38.7179
Europium	0.0010	0.0094	0.0074	0.0009	0.0085	0.0064	0.0010	0.0090	0.8682	0.0011	0.0052	0.2692
Iron	0.0648	0.6051	0.4730	0.0429	0.4039	0.3038	0.0419	0.3955	38.0909	0.3310	1.6539	84.8718
La	0.0002	0.0017	0.0013	0.0002	0.0016	0.0012	0.0002	0.0017	0.1591	0.0002	0.0009	0.0451
Lead	0.0010	0.0097	0.0076	0.0010	0.0096	0.0072	0.0010	0.0097	0.9364	0.0049	0.0242	1.2436
Lithium	0.0006	0.0054	0.0042	0.0006	0.0054	0.0040	0.0006	0.0057	0.5527	0.0006	0.0030	0.1538
*Mg	0.1280	1.1954		0.1270	1.1955		0.1170	1.1043		0.1150	0.5746	
Mn	0.0016	0.0151	0.0118	0.0014	0.0127	0.0096	0.0013	0.0126	1.2182	0.0077	0.0386	1.9795
Mo	0.0007	0.0061	0.0048	0.0002	0.0022	0.0017	0.0001	0.0013	0.1282	0.0013	0.0062	0.3205
Nd	0.0011	0.0104	0.0081	0.0002	0.0016	0.0012	0.0006	0.0059	0.5664	0.0017	0.0083	0.4282
Nickel	0.0002	0.0019	0.0015	0.0002	0.0015	0.0012	0.0002	0.0015	0.1418	0.0016	0.0079	0.4051
Pr	0.0000	0.0004	0.0003	0.0000	0.0003	0.0003	0.0000	0.0004	0.0355	0.0000	0.0002	0.0105
Ruthenium	0.0005	0.0050	0.0039	0.0002	0.0017	0.0013	0.0001	0.0012	0.1173	0.0003	0.0016	0.0844
Samarium	0.0013	0.0119	0.0093	0.0013	0.0118	0.0089	0.0014	0.0129	1.2455	0.0013	0.0066	0.3385
*Strontium	0.0179	0.1672		0.0175	0.1647		0.0177	0.1671		0.0880	0.4397	
Terbium	0.0000	0.0002	0.0001	0.0000	0.0001	0.0001	0.0000	0.0002	0.0145	0.0000	0.0001	0.0064
Titanium	0.0017	0.0160	0.0125	0.0015	0.0141	0.0106	0.0017	0.0157	1.5091	0.0093	0.0463	2.3769
*Zirconium	0.0122	0.1139		0.0077	0.0721		0.0095	0.0897		0.0111	0.0555	
mg, Metals Found	10.7081	100.0000	1.3872	10.6227	100.0000	0.4999	10.5951	100.0000	82.6109	20.0134	100.0000	158.7821
mg, Filter Loading	13.7000			14.1200			0.1100			0.3900		

*High Al, Ba, B, Mg, Europium (?), Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti, Zr

Table A2.10B.36 Test 2/10B Marple #3 Elemental Analyses, Stages 4-7

2/10B	STAGE 4			STAGE 5			STAGE 6			STAGE 7		
M #3	Particle size 6.0 µm			Particle size 3.5 µm			Particle size 1.55 µm			Particle size 0.93 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	2.2200	21.0158		2.2300	20.9742		1.4400	22.1862		1.5000	23.1608	
Antimony	0.0000	0.0004	0.0076	0.0000	0.0004	0.0049	0.0000	0.0005	0.0091	0.0000	0.0004	0.0290
*Barium	4.6300	43.8302		4.5600	42.8889		2.8700	44.2183		2.8900	44.6232	
*Boron	3.3300	31.5237		3.4400	32.3548		1.9300	29.7356		1.9400	29.9546	
Cerium	0.1030	0.9751	21.0204	0.0057	0.0533	0.6443	0.0048	0.0744	1.4636	0.0014	0.0221	1.4300
Cesium	0.0023	0.0216	0.4653	0.0081	0.0765	0.9239	0.0102	0.1572	3.0909	0.0035	0.0536	3.4700
Chromium	0.0010	0.0091	0.1965	0.0011	0.0104	0.1261	0.0008	0.0131	0.2570	0.0007	0.0109	0.7040
Copper	0.0381	0.3607	7.7755	0.1110	1.0440	12.6136	0.0800	1.2326	24.2424	0.0225	0.3474	22.5000
Europium	0.0011	0.0105	0.2265	0.0012	0.0117	0.1409	0.0007	0.0106	0.2088	0.0005	0.0084	0.5470
Iron	0.0759	0.7185	15.4898	0.1160	1.0910	13.1818	0.0537	0.8274	16.2727	0.0259	0.3999	25.9000
La	0.0002	0.0017	0.0369	0.0002	0.0017	0.0205	0.0001	0.0017	0.0339	0.0001	0.0017	0.1100
Lead	0.0010	0.0098	0.2102	0.0011	0.0102	0.1227	0.0007	0.0108	0.2130	0.0007	0.0100	0.6500
Lithium	0.0006	0.0058	0.1253	0.0006	0.0058	0.0695	0.0004	0.0060	0.1173	0.0004	0.0057	0.3700
*Mg	0.1220	1.1549		0.1180	1.1098		0.0722	1.1124		0.0687	1.0608	
Mn	0.0017	0.0157	0.3388	0.0021	0.0199	0.2409	0.0013	0.0203	0.4000	0.0013	0.0196	1.2700
Mo	0.0003	0.0031	0.0665	0.0011	0.0107	0.1295	0.0016	0.0243	0.4788	0.0005	0.0073	0.4710
Nd	0.0019	0.0181	0.3898	0.0003	0.0029	0.0355	0.0002	0.0030	0.0594	0.0001	0.0019	0.1210
Nickel	0.0002	0.0023	0.0498	0.0002	0.0023	0.0282	0.0002	0.0027	0.0527	0.0003	0.0044	0.2840
Pr	0.0000	0.0004	0.0086	0.0000	0.0004	0.0043	0.0000	0.0004	0.0073	0.0000	0.0004	0.0240
Ruthenium	0.0005	0.0043	0.0937	0.0013	0.0123	0.1489	0.0010	0.0149	0.2936	0.0002	0.0038	0.2440
Samarium	0.0013	0.0126	0.2714	0.0013	0.0125	0.1511	0.0008	0.0126	0.2473	0.0008	0.0120	0.7740
*Strontium	0.0180	0.1704		0.0187	0.1759		0.0108	0.1664		0.0105	0.1621	
Terbium	0.0000	0.0002	0.0051	0.0000	0.0001	0.0014	0.0000	0.0002	0.0030	0.0000	0.0002	0.0100
Titanium	0.0018	0.0169	0.3633	0.0020	0.0183	0.2216	0.0015	0.0236	0.4636	0.0016	0.0239	1.5500
*Zirconium	0.0125	0.1183		0.0119	0.1119		0.0094	0.1450		0.0068	0.1050	
mg, Metals Found	10.5635	100.0000	47.1410	10.6321	100.0000	28.8097	6.4905	100.0000	47.9145	6.4765	100.0000	60.4580
mg, Filter Loading	0.4900			0.8800			0.3300			0.1000		

*High Al, Ba, B, Mg, Europium (?), Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti, Zr

Table A2.10B.37 Test 2/10B Marple #3 Elemental Analyses, Stages 8-9 & LPS #3

2/10B	STAGE 8			STAGE 9				LPS #1			
M #3	Particle size 0.52 µm			Particle size final, <0.5 µm				S1: ~82-100 µm	S2: ~65-82 µm	S3: ~48-65 µm	S4: ~30-48 µm
	mg	% detect	% loading	mg	% detect	% loading		mg	mg	mg	mg
*Aluminum	1.3400	21.9508		1.6300	22.3169			2.0700	1.8900	2.0000	1.9600
Antimony	0.0000	0.0005	0.0165	0.0000	0.0005	0.0236		0.0001	0.0000	0.0000	0.0000
*Barium	2.7200	44.5569		3.2800	44.9077			4.3600	4.0400	3.9500	3.8900
*Boron	1.8800	30.7967		2.2300	30.5318			3.0300	2.7100	2.7200	2.8800
Cerium	0.0069	0.1135	4.0765	0.0030	0.0413	2.1571		0.0137	0.0006	0.0011	0.0037
Cesium	0.0051	0.0829	2.9765	0.0026	0.0352	1.8357		0.0002	0.0002	0.0004	0.0014
Chromium	0.0007	0.0112	0.4018	0.0007	0.0097	0.5050		0.0010	0.0010	0.0011	0.0013
Copper	0.0347	0.5684	20.4118	0.0163	0.2232	11.6429		0.0085	0.0057	0.0120	0.0488
Europium	0.0005	0.0089	0.3206	0.0006	0.0084	0.4407		0.0008	0.0008	0.0008	0.0008
Iron	0.0262	0.4292	15.4118	0.0271	0.3710	19.3571		0.0358	0.0384	0.0647	0.0977
La	0.0001	0.0017	0.0606	0.0001	0.0019	0.0986		0.0002	0.0002	0.0002	0.0002
Lead	0.0006	0.0105	0.3759	0.0009	0.0120	0.6286		0.0012	0.0011	0.0011	0.0013
Lithium	0.0003	0.0057	0.2035	0.0004	0.0060	0.3114		0.0005	0.0005	0.0005	0.0005
*Mg	0.0652	1.0681		0.0872	1.1939			0.1000	0.1030	0.1050	0.1040
Mn	0.0009	0.0147	0.5288	0.0010	0.0141	0.7357		0.0013	0.0012	0.0014	0.0019
Mo	0.0009	0.0142	0.5088	0.0004	0.0057	0.2957		0.0001	0.0001	0.0001	0.0003
Nd	0.0002	0.0026	0.0924	0.0002	0.0026	0.1350		0.0004	0.0002	0.0002	0.0002
Nickel	0.0001	0.0024	0.0865	0.0001	0.0014	0.0714		0.0002	0.0002	0.0002	0.0004
Pr	0.0000	0.0004	0.0129	0.0000	0.0004	0.0214		0.0000	0.0000	0.0000	0.0000
Ruthenium	0.0004	0.0061	0.2200	0.0002	0.0022	0.1171		0.0000	0.0000	0.0001	0.0004
Samarium	0.0007	0.0120	0.4306	0.0009	0.0120	0.6279		0.0011	0.0011	0.0011	0.0011
*Strontium	0.0100	0.1632		0.0118	0.1616			0.0150	0.0152	0.0154	0.0158
Terbium	0.0000	0.0002	0.0059	0.0000	0.0001	0.0071		0.0000	0.0000	0.0000	0.0000
Titanium	0.0013	0.0215	0.7706	0.0014	0.0196	1.0214		0.0019	0.0018	0.0018	0.0019
*Zirconium	0.0097	0.1581		0.0088	0.1208			0.0011	0.0082	0.0081	0.0090
mg, Metals Found	6.1046	100.0000	46.9118	7.3039	100.0000	40.0336		9.6429	8.8196	8.8853	9.0209
mg, Filter Loading	0.1700			0.1400							

*High Al, Ba, B, Mg, Europium, Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti, Zr

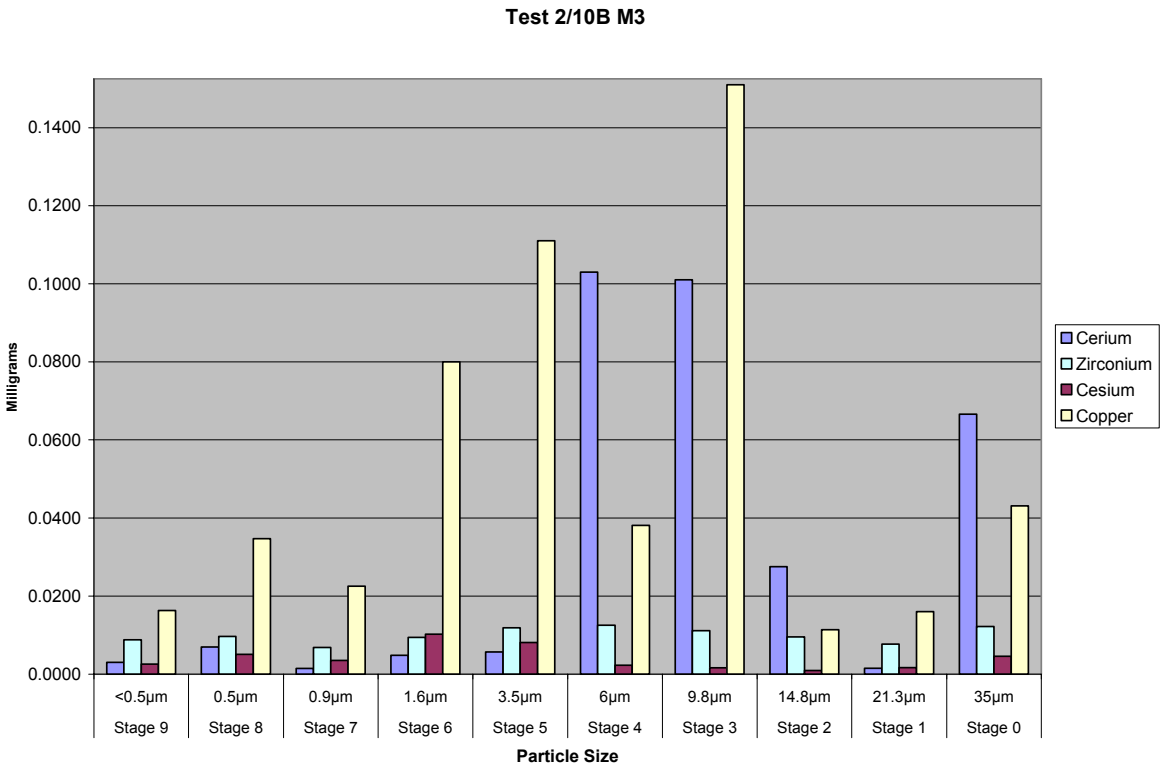


Figure A2.10B.35 Test 2/10B Marple #3 Metals Analysis Distribution, mg

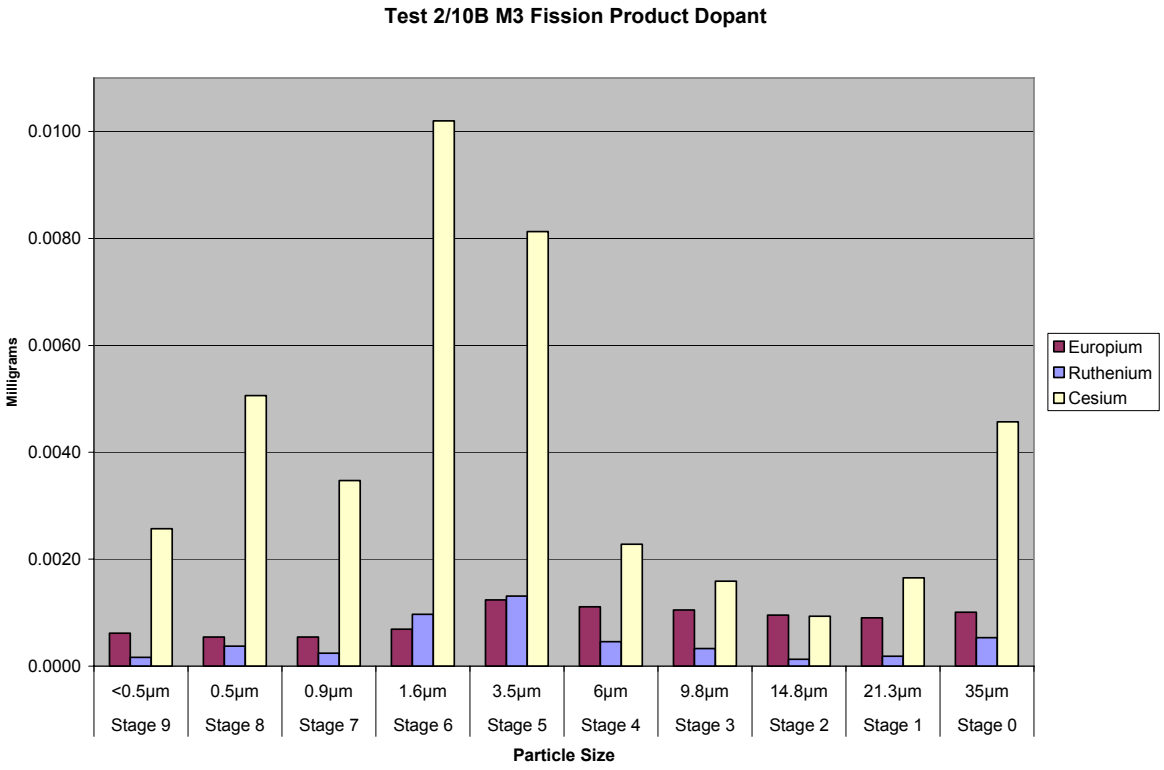


Figure A2.10B.36 Test 2/10B Marple #3 Fission Product Dopant Distribution, mg

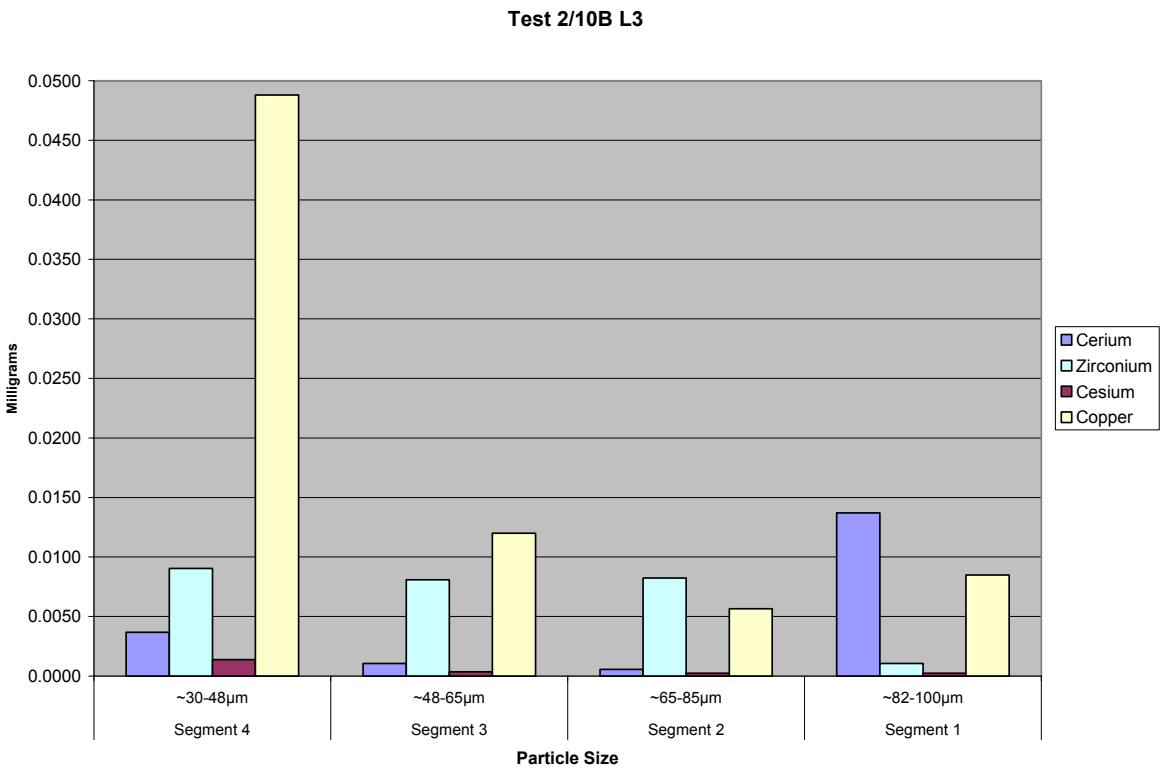


Figure A2.10B.37 Test 2/10B LPS #3 Metals Analysis Distribution, mg

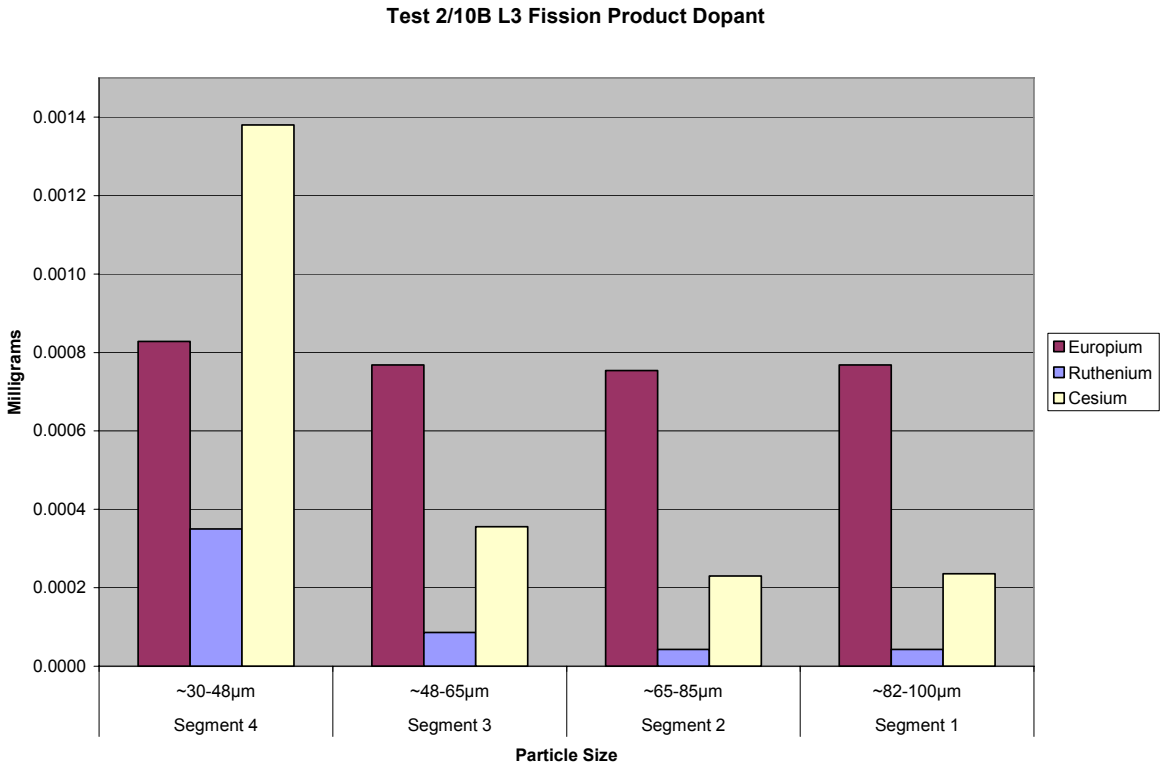


Figure A2.10B.38 Test 2/10B LPS #3 Fission Product Dopant Distribution, mg

A.2.10C Test 2/10C Analyses and Results

Particulates from test 2/10C were sampled using four independent Large Particle Separator and Marple impactor systems. In addition, multiple separate impact particle debris samples were collected by a HEPA vacuum system and a newly installed pre-separator paper liner (collection bag), rather than with smaller filter socks, as previously used. The impact particle debris was subsequently mechanically sieved and chemically analyzed by ICP-MS. Surface deposited particle samples were also obtained from the exterior and interior of each of the four internal chamber sampling tubes.

Gravimetric and Debris Analyses: Graphs of gravimetric particle size distributions from the four 2/10C Marple impactors, plus the mass concentrations, are presented in Figures A2.10C.39 to Figure A2.10C.43. The weight distribution of the sieved particle impact debris is presented in Table A2.10C.38. Table A2.10C.39 contains the measured impact debris elemental analysis, in weight percent, for the particles from 90 to < 25 μm (geometric) size, or 234 to <65 μm AED for CeO_2 pellets. The weight percent distribution of metals on the impact debris sieved fractions is plotted in Figure A2.10C.44 and Figure A2.10C.45 provides the similar impact debris weight percent distribution of fission product dopants.

Marple and LPS Particle Element Analyses: Chemical analyses were performed on three of the Marple and LPS particle collection systems, the fourth Marple and LPS samples were held in reserve. Each Large Particle Sampler fiberglass substrate was cut into four separate pieces prior to chemical dissolution and elemental analysis by ICP-MS. These LPS segments cover the nominal particle size range of: Segment #1 is ~82-100 μm AED, Segment #2 is ~65-82 μm AED, Segment #3 is ~48-65 μm AED, and Segment #4 is ~30-48 μm AED. The nomenclature for the Marple/LPS systems was somewhat modified for this test since alternate, identical apparatus was rotated into usage. The sampling system locations on top of the test chamber are labeled #1, #2, #3, and #4, as shown in Figure 4.7. However, the marked identifications on the Marples and LPS apparati connected to these locations were 003, 002, 005, and 006, respectively. In the tables and figures that follow for test 2/10C, location #1=M3 & L3, location #2=M2 & L2, location #3=M5 & L6, and location #4=M6 & L6, respectively.

All Marple M2 elemental analyses are listed in Tables A2.10C.40 to A2.10C.42 and are plotted in Figure A2.10C.46 for metals and Figure A2.10C.47 for fission product dopants. All LPS L2 elemental analyses are also listed in Table A2.10C.42 and are plotted in Figure A2.10C.48 for metals and Figure A2.10C.49 for fission product dopants.

All Marple M5 elemental analyses are listed in Tables A2.10C.43 to A2.10C.45 and are plotted in Figure A2.10C.50 for metals and Figure A2.10C.51 for fission product dopants. All LPS L5 elemental analyses are also listed in Table A2.10C.45 and are plotted in Figure A2.10C.52 for metals and Figure A2.10C.53 for fission product dopants.

All Marple M6 elemental analyses are listed in Tables A2.10C.46 to A2.10C.48 and are plotted in Figure A2.10C.54 for metals and Figure A2.10B.55 for fission product dopants. All LPS L6 elemental analyses are also listed in Table A2.10C.48 and are plotted in Figure A2.10C.56 for metals and Figure A2.10C.57 for fission product dopants.

NOTE: The final row “mg, Filter Loading” in tables that list the elemental analyses for Marple and LPS samples may be difficult to interpret. This is because the metal elements

content for aluminum, barium, magnesium, strontium, and zirconium have not been included. These elements were all present as significant impurities contained within the fiberglass substrates used, and not detected until later. So, the "corrected" values for "mg, Filter Loading" are actually listed as lower in value than the analyzed "mg, metals found." The primary impact of this high impurity content in the fiberglass substrate is that measured values for "fission product content" for added dopant strontium has been masked. The strontium dopant content values are, therefore, unreliable and are not presented in the figures along with other measured fission product dopants.

Table A2.10C.38 Test 2/10C Weight Distribution of Impact Debris

Sieve #	Opening Size	AED Size for CeO_2	Weight, g Retained	Weight, g Passed	Percent Passed	Percent Retained
18	1.00 mm	2600 µm				
35	500 µm	1300 µm				
60	250 µm	650 µm				
120	125 µm	325 µm				
170	90 µm	234 µm				
200	75 µm	193 µm				
400	38 µm	99 µm				
600	25 µm	65 µm				
totals						

[DATA NOT AVAILABLE]

Table A2.10C.39 Test 2/10C Impact Debris Metals Weight Percent Distribution

Test 2/10C	90 µm	75 µm	38 µm	≤25 µm
Aluminum				
Antimony				
Barium				
Boron				
Cerium				
Cesium				
Chromium				
Copper				
Europium				
Iron				
Lanthanum				
Lead				
Lithium				
Magnesium				
Manganese				
Nickel				
Praseodymium				
Ruthenium				
Samarium				
Strontium				
Terbium				
Titanium				
Zirconium				
Totals				
*Others				

*Sb, Ba, B, Cr, La, Pb, Li, Mg, Mn, Mo, Nd, Ni, Pr, Sm, Tb, Ti,

[DATA NOT AVAILABLE]

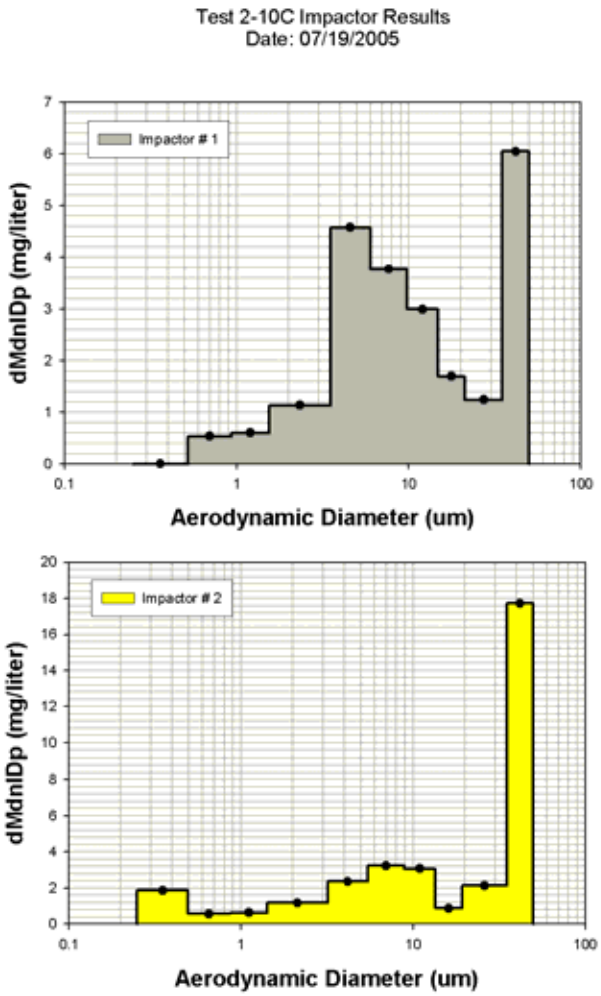


Figure A2.10C.39 Test 2/10C Marple #1 Size Distribution

Figure A2.10C.40 Test 2/10C Marple #2 Size Distribution

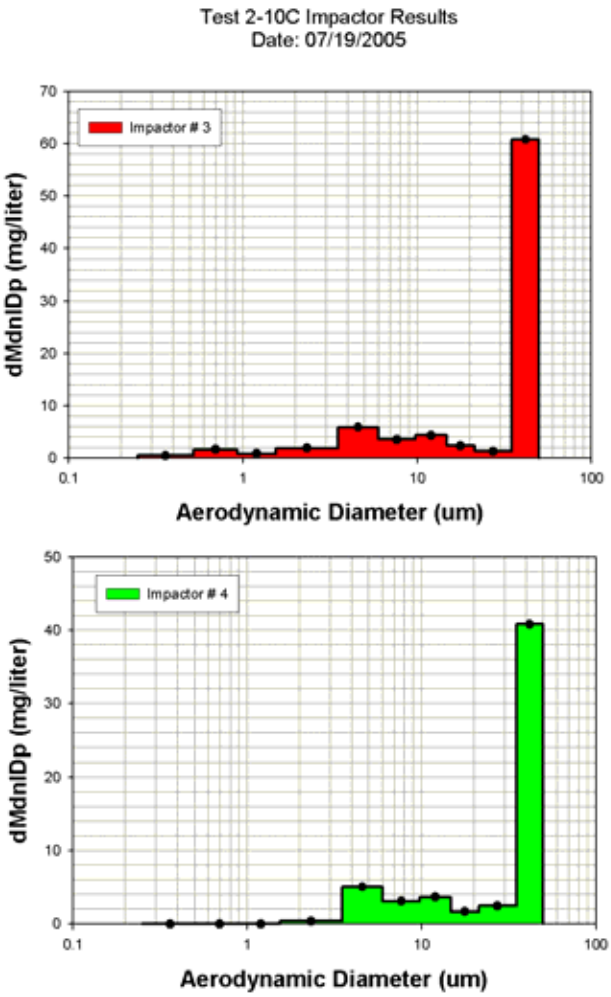


Figure A2.10C.41 Test 2/10C Marple #3 Size Distribution

Figure A2.10C.42 Test 2/10C Marple #4 Size Distribution

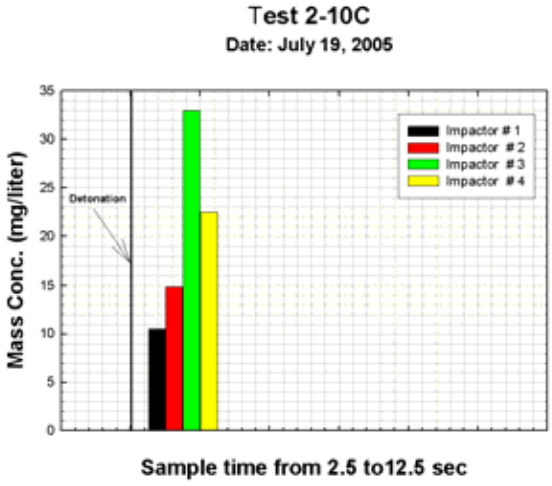


Figure A2.10C.43 Test 2/10C Marple Impactor Mass Concentration Data

[DATA NOT AVAILABLE]

Figure A2.10C.44 Test 2/10C Metals Weight Percent Distribution, Impact Debris Fractions

[DATA NOT AVAILABLE]

Figure A2.10C.45 Test 2/10C Fission Product Weight Percent Distribution of Impact Debris

Table A2.10B.40 Test 2/10C Marple M2 Elemental Analyses, Stages 0-3

2/10C	STAGE 0			STAGE 1			STAGE 2			STAGE 3		
M2	Particle size 35 µm			Particle size 21.3 µm			Particle size 14.8 µm			Particle size 9.8 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	1.5500	23.2557		1.4100	22.1331		1.3400	22.5532		1.4200	22.9011	
Antimony	0.0001	0.0019	0.0149	0.0001	0.0020	0.0313	0.0001	0.0021	0.1250	0.0001	0.0020	0.0313
*Barium	2.5100	37.6593		2.5700	40.3419		2.3600	39.7206		2.4200	39.0286	
*Boron	2.2700	34.0584		2.1700	34.0630		2.0700	34.8397		2.1200	34.1903	
Cerium	0.0700	1.0503	8.3333	0.0308	0.4835	7.7000	0.0207	0.3484	20.7000	0.0434	0.6999	10.8500
Cesium	0.0062	0.0936	0.7429	0.0026	0.0408	0.6500	0.0012	0.0199	1.1800	0.0012	0.0197	0.3050
Chromium	0.0013	0.0198	0.1571	0.0014	0.0215	0.3425	0.0011	0.0177	1.0500	0.0012	0.0189	0.2925
Copper	0.0706	1.0593	8.4048	0.0290	0.4552	7.2500	0.0165	0.2777	16.5000	0.0277	0.4467	6.9250
Europium	0.0011	0.0164	0.1298	0.0008	0.0131	0.2088	0.0007	0.0120	0.7110	0.0009	0.0147	0.2273
Iron	0.0792	1.1883	9.4286	0.0489	0.7676	12.2250	0.0371	0.6244	37.1000	0.0673	1.0854	16.8250
La	0.0001	0.0015	0.0120	0.0001	0.0016	0.0253	0.0001	0.0015	0.0920	0.0001	0.0016	0.0253
Lead	0.0007	0.0099	0.0789	0.0006	0.0101	0.1605	0.0006	0.0102	0.6060	0.0006	0.0099	0.1528
Lithium	0.0005	0.0075	0.0595	0.0005	0.0078	0.1250	0.0005	0.0084	0.5000	0.0005	0.0081	0.1250
*Mg	0.0789	1.1838		0.0837	1.3139		0.0739	1.2438		0.0760	1.2257	
Mn	0.0014	0.0213	0.1690	0.0011	0.0174	0.2775	0.0010	0.0161	0.9560	0.0012	0.0197	0.3050
Mo	0.0002	0.0028	0.0224	0.0001	0.0015	0.0233	0.0000	0.0006	0.0370	0.0001	0.0010	0.0155
Nd	0.0014	0.0212	0.1679	0.0002	0.0034	0.0538	0.0002	0.0028	0.1640	0.0001	0.0023	0.0353
Nickel	0.0003	0.0042	0.0331	0.0002	0.0037	0.0595	0.0002	0.0038	0.2280	0.0003	0.0042	0.0648
Pr	0.0000	0.0003	0.0027	0.0000	0.0003	0.0055	0.0000	0.0003	0.0200	0.0000	0.0004	0.0055
Ruthenium	0.0007	0.0099	0.0788	0.0002	0.0039	0.0615	0.0001	0.0022	0.1310	0.0002	0.0036	0.0565
Samarium	0.0010	0.0143	0.1138	0.0010	0.0152	0.2428	0.0009	0.0147	0.8730	0.0009	0.0148	0.2295
*Strontium	0.0113	0.1695		0.0111	0.1742		0.0104	0.1750		0.0107	0.1726	
Terbium	0.0000	0.0003	0.0024	0.0000	0.0002	0.0030	0.0000	0.0002	0.0100	0.0000	0.0002	0.0038
Titanium	0.0013	0.0194	0.1536	0.0012	0.0193	0.3075	0.0010	0.0166	0.9850	0.0011	0.0184	0.2850
*Zirconium	0.0087	0.1311		0.0067	0.1056		0.0052	0.0880		0.0069	0.1105	
Others	0.1675	2.5129		0.1401	2.1986		0.1174	1.9752		0.1505	2.4271	
mg, Metals Found	6.6650	100.0000	28.1055	6.3705	100.0000	29.7525	5.9415	100.0000	81.9680	6.2006	100.0000	36.7598
mg, Filter Loading	2.0000			0.4000			0.1000			0.4000		

*High Al, Ba, B, Mg, Europium (?), Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A2.10C.41 Test 2/10C Marple M2 Elemental Analyses, Stages 4-7

2/10C	STAGE 4			STAGE 5			STAGE 6			STAGE 7		
M2	Particle size 6.0 µm			Particle size 3.5 µm			Particle size 1.55 µm			Particle size 0.93 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	1.6100	24.7516		1.4300	21.9158		1.5900	24.5627		1.5200	24.1932	
Antimony	0.0001	0.0019	0.0250	0.0001	0.0019	0.0313	0.0001	0.0019	0.0417	0.0001	0.0020	0.1250
*Barium	2.4900	38.2804		2.5300	38.7741		2.4900	38.4662		2.4300	38.6773	
*Boron	2.1700	33.3608		2.2300	34.1764		2.1800	33.6772		2.1600	34.3798	
Cerium	0.0458	0.7041	9.1600	0.0852	1.3058	21.3000	0.0283	0.4372	9.4333	0.0085	0.1356	8.5200
Cesium	0.0016	0.0246	0.3200	0.0050	0.0772	1.2600	0.0039	0.0598	1.2900	0.0036	0.0565	3.5500
Chromium	0.0011	0.0169	0.2200	0.0011	0.0161	0.2625	0.0010	0.0161	0.3467	0.0011	0.0170	1.0700
Copper	0.0297	0.4566	5.9400	0.0612	0.9379	15.3000	0.0347	0.5361	11.5667	0.0272	0.4329	27.2000
Europium	0.0009	0.0139	0.1804	0.0011	0.0166	0.2700	0.0008	0.0119	0.2570	0.0007	0.0106	0.6670
Iron	0.0575	0.8840	11.5000	0.0793	1.2153	19.8250	0.0438	0.6766	14.6000	0.0337	0.5364	33.7000
La	0.0001	0.0016	0.0206	0.0001	0.0015	0.0243	0.0001	0.0016	0.0340	0.0001	0.0016	0.1030
Lead	0.0006	0.0097	0.1258	0.0006	0.0096	0.1568	0.0006	0.0094	0.2023	0.0006	0.0095	0.5980
Lithium	0.0005	0.0077	0.1000	0.0005	0.0077	0.1250	0.0005	0.0077	0.1667	0.0005	0.0080	0.5000
*Mg	0.0748	1.1499		0.0756	1.1586		0.0789	1.2189		0.0771	1.2272	
Mn	0.0012	0.0178	0.2320	0.0014	0.0210	0.3425	0.0010	0.0161	0.3467	0.0010	0.0153	0.9590
Mo	0.0001	0.0008	0.0100	0.0001	0.0016	0.0265	0.0001	0.0012	0.0263	0.0001	0.0011	0.0680
Nd	0.0001	0.0009	0.0122	0.0016	0.0248	0.4050	0.0002	0.0027	0.0593	0.0001	0.0021	0.1300
Nickel	0.0002	0.0031	0.0408	0.0002	0.0032	0.0525	0.0002	0.0025	0.0533	0.0002	0.0024	0.1520
Pr	0.0000	0.0003	0.0044	0.0000	0.0003	0.0055	0.0000	0.0003	0.0073	0.0000	0.0003	0.0210
Ruthenium	0.0003	0.0042	0.0550	0.0006	0.0098	0.1595	0.0004	0.0055	0.1180	0.0002	0.0038	0.2410
Samarium	0.0009	0.0144	0.1868	0.0009	0.0141	0.2305	0.0009	0.0143	0.3077	0.0009	0.0145	0.9100
*Strontium	0.0111	0.1706		0.0110	0.1686		0.0104	0.1607		0.0103	0.1639	
Terbium	0.0000	0.0002	0.0030	0.0000	0.0003	0.0055	0.0000	0.0002	0.0040	0.0000	0.0002	0.0100
Titanium	0.0012	0.0178	0.2320	0.0013	0.0198	0.3225	0.0011	0.0171	0.3700	0.0011	0.0181	1.1400
*Zirconium	0.0069	0.1061		0.0080	0.1220		0.0062	0.0962		0.0057	0.0906	
Others	0.1393	2.1410		0.1639	2.5125		0.1294	1.9985		0.1173	1.8663	
mg, Metals Found	6.5046	100.0000	28.3680	6.5250	100.0000	60.1048	6.4732	100.0000	39.2310	6.2828	100.0000	79.6640
mg, Filter Loading	0.5000			0.4000			0.3000			0.1000		

*High Al, Ba, B, Mg, Europium (?), Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A2.10C.42 Test 2/10C Marple M2 Elemental Analyses, Stages 8-9 & LPS L2

2/10C	STAGE 8			STAGE 9				LPS L2			
M2	Particle size 0.52 µm			Particle size final, <0.5 µm				S1: ~82-100 µm	S2: ~65-82 µm	S3: ~48-65 µm	S4: ~30-48 µm
	mg	% detect	% loading	mg	% detect	% loading		mg	mg	mg	mg
*Aluminum	1.4300	23.1281		1.8400	25.5450			0.8050	0.7100	0.7500	0.7390
Antimony	0.0001	0.0020	0.1250	0.0001	0.0017	0.0313		0.0001	0.0001	0.0001	0.0001
*Barium	2.4100	38.9781		2.7300	37.9010			1.2700	1.1500	1.2700	1.2000
*Boron	2.1600	34.9348		2.3900	33.1807			1.0300	0.9270	0.9650	0.9940
Cerium	0.0050	0.0809	5.0000	0.0064	0.0891	1.6050		0.0008	0.0003	0.0008	0.0041
Cesium	0.0066	0.1064	6.5800	0.0099	0.1376	2.4775		0.0001	0.0000	0.0001	0.0001
Chromium	0.0010	0.0165	1.0200	0.0013	0.0175	0.3150		0.0009	0.0008	0.0009	0.0010
Copper	0.0423	0.6841	42.3000	0.0627	0.8705	15.6750		0.0009	0.0007	0.0010	0.0035
Europium	0.0006	0.0103	0.6380	0.0007	0.0101	0.1815		0.0003	0.0003	0.0003	0.0003
Iron	0.0307	0.4965	30.7000	0.0381	0.5289	9.5250		0.0145	0.0117	0.0127	0.0156
La	0.0001	0.0016	0.0970	0.0001	0.0019	0.0338		0.0001	0.0000	0.0001	0.0001
Lead	0.0006	0.0101	0.6260	0.0009	0.0122	0.2205		0.0004	0.0003	0.0004	0.0004
Lithium	0.0005	0.0081	0.5000	0.0005	0.0069	0.1250		0.0005	0.0005	0.0005	0.0005
*Mg	0.0747	1.2082		0.0958	1.3300			0.0336	0.0300	0.0333	0.0300
Mn	0.0010	0.0158	0.9780	0.0012	0.0162	0.2925		0.0004	0.0003	0.0003	0.0004
Mo	0.0001	0.0023	0.1410	0.0002	0.0031	0.0560		0.0000	0.0000	0.0000	0.0000
Nd	0.0002	0.0034	0.2130	0.0003	0.0042	0.0755		0.0001	0.0000	0.0001	0.0001
Nickel	0.0002	0.0025	0.1520	0.0002	0.0026	0.0468		0.0001	0.0001	0.0001	0.0002
Pr	0.0000	0.0003	0.0200	0.0000	0.0004	0.0073		0.0000	0.0000	0.0000	0.0000
Ruthenium	0.0003	0.0050	0.3070	0.0004	0.0056	0.1010		0.0000	0.0000	0.0000	0.0000
Samarium	0.0009	0.0146	0.9000	0.0010	0.0140	0.2525		0.0004	0.0004	0.0005	0.0004
*Strontium	0.0107	0.1731		0.0121	0.1680			0.0058	0.0054	0.0060	0.0056
Terbium	0.0000	0.0002	0.0100	0.0000	0.0002	0.0028		0.0000	0.0000	0.0000	0.0000
Titanium	0.0010	0.0160	0.9880	0.0012	0.0171	0.3075		0.0006	0.0005	0.0007	0.0006
*Zirconium	0.0063	0.1012		0.0098	0.1354			0.0021	0.0018	0.0023	0.0021
Others	0.1118	1.8083		0.1417	1.9671			0.0520	0.0452	0.0500	0.0498
mg, Metals Found	6.1830	100.0000	91.2950	7.2030	100.0000	31.3313		3.1667	2.8403	3.0451	2.9982
mg, Filter Loading	0.1000			0.4000							

*High Al, Ba, B, Mg, Europium (?), Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

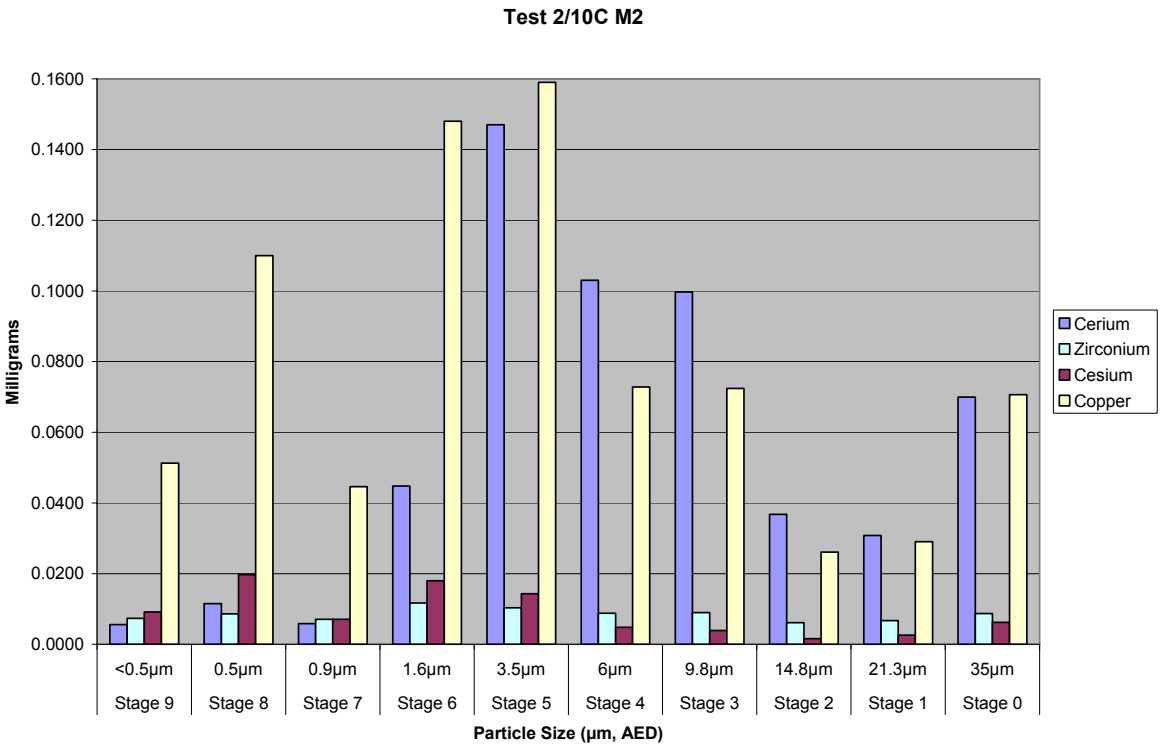


Figure A2.10C.46 Test 2/10C Marple M2 Metals Analysis Distribution, mg

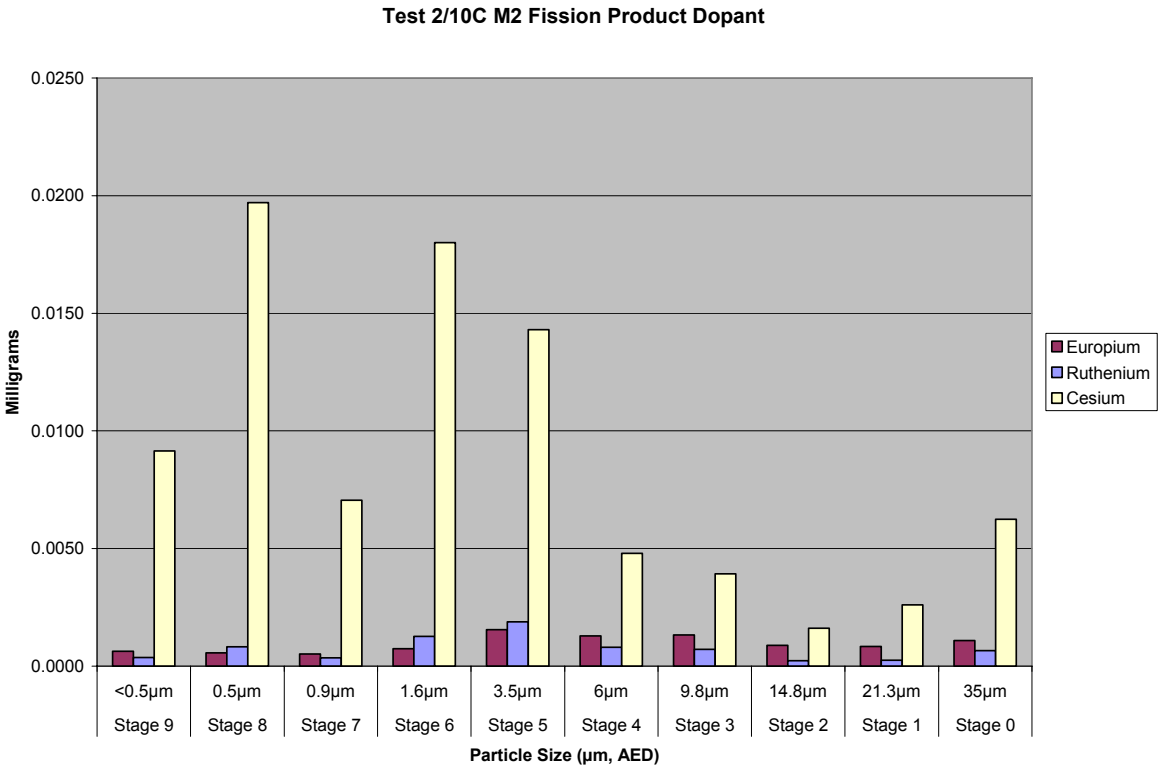


Figure A2.10C.47 Test 2/10C Marple M2 Fission Product Dopant Distribution, mg

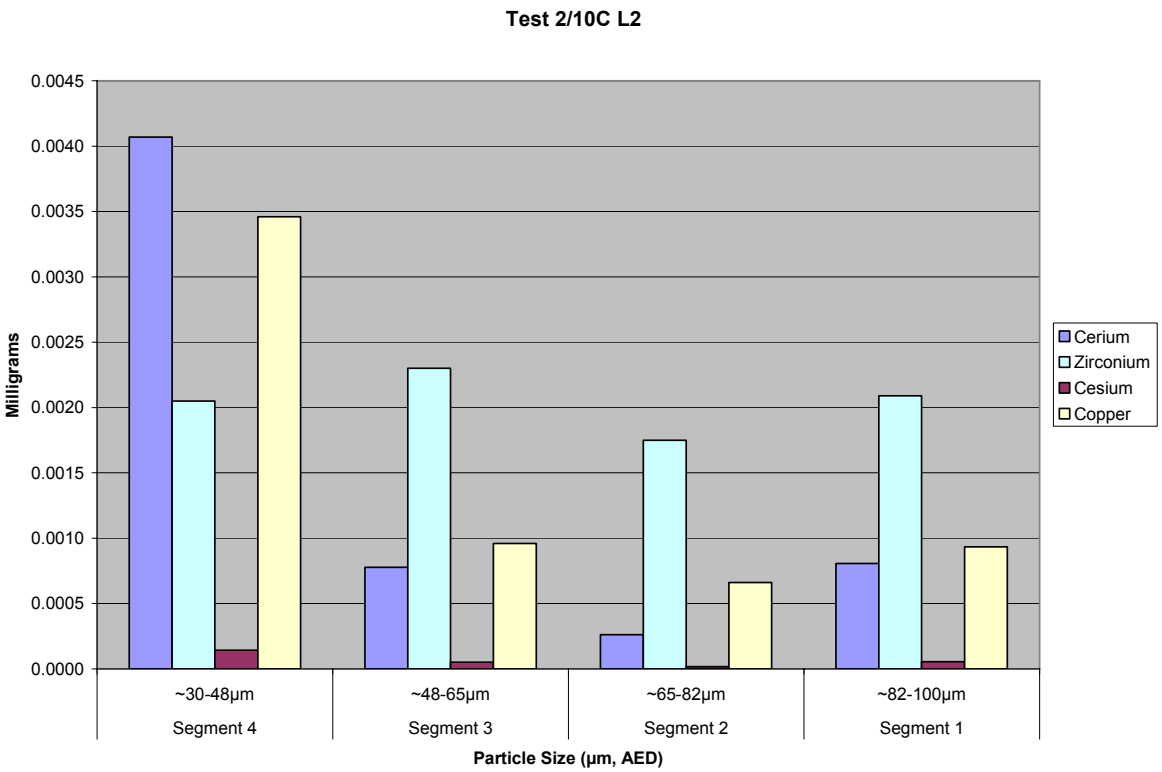


Figure A2.10C.48 Test 2/10C LPS L2 Metals Analysis Distribution, mg

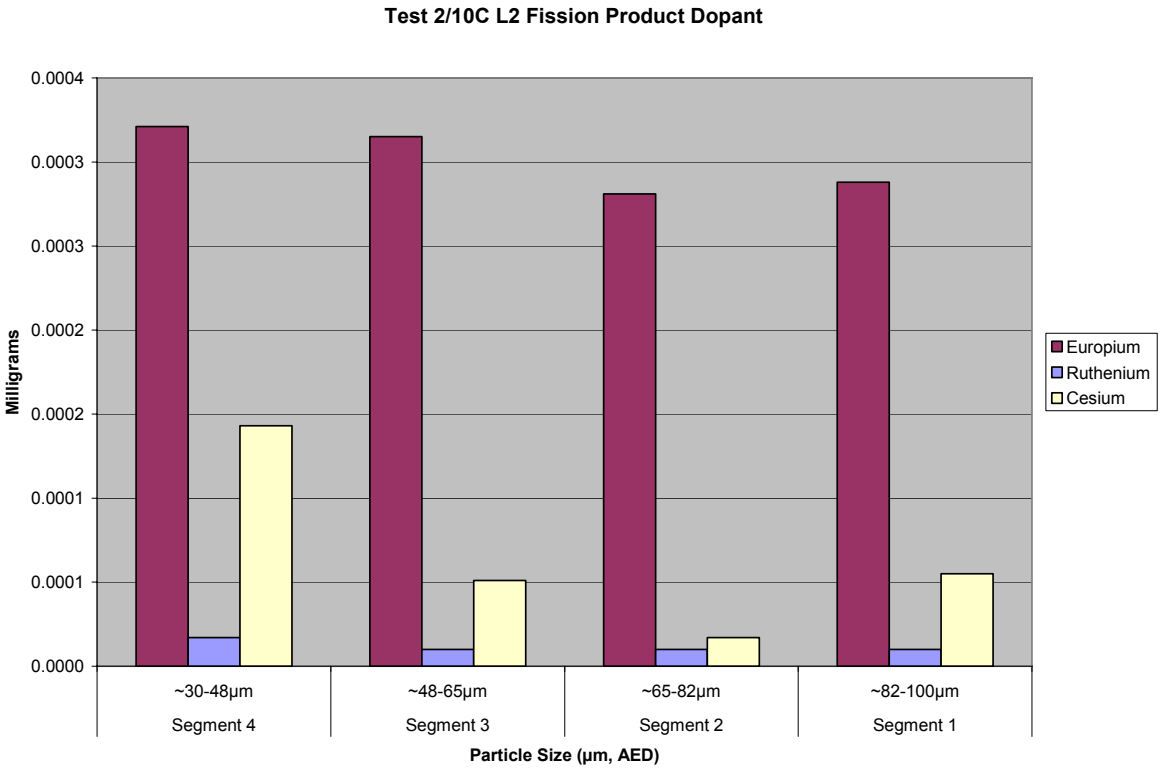


Figure A2.10C.49 Test 2/10C LPS L2 Fission Product Dopant Distribution, mg

Table A2.10C.43 Test 2/10C Marple M5 Elemental Analyses, Stages 0-3

2/10C	STAGE 0			STAGE 1			STAGE 2			STAGE 3		
M5	Particle size 35 µm			Particle size 21.3 µm			Particle size 14.8 µm			Particle size 9.8 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	1.5500	23.2557		1.4100	22.1331		1.4300	23.3216		1.4900	23.2057	
Antimony	0.0001	1.1062	0.0018	0.0001	1.1261	0.0625	0.0001	1.2376	0.0463	0.0001	1.1905	0.0219
*Barium	2.5100	37.6593		2.5700	40.3419		2.4200	39.4674		2.5400	39.5587	
*Boron	2.2700	34.0584		2.1700	34.0630		2.0700	33.7593		2.0000	31.1486	
Cerium	0.0700	1.0503	1.0072	0.0308	0.4835	15.4000	0.0368	0.6002	13.6296	0.0997	1.5528	17.4912
Cesium	0.0062	0.0936	0.0898	0.0026	0.0408	1.3000	0.0016	0.0263	0.5963	0.0039	0.0611	0.6877
Chromium	0.0013	0.0198	0.0190	0.0014	0.0215	0.6850	0.0011	0.0186	0.4222	0.0012	0.0187	0.2105
Copper	0.0706	1.0593	1.0158	0.0290	0.4552	14.5000	0.0261	0.4257	9.6667	0.0724	1.1276	12.7018
Europium	0.0011	0.0164	0.0157	0.0008	0.0131	0.4175	0.0009	0.0144	0.3274	0.0013	0.0207	0.2333
Iron	0.0792	1.1883	1.1396	0.0489	0.7676	24.4500	0.0525	0.8562	19.4444	0.1110	1.7287	19.4737
La	0.0001	0.0015	0.0015	0.0001	0.0016	0.0505	0.0001	0.0017	0.0385	0.0001	0.0017	0.0188
Lead	0.0007	0.0099	0.0095	0.0006	0.0101	0.3210	0.0006	0.0095	0.2148	0.0006	0.0094	0.1061
Lithium	0.0005	0.0075	0.0072	0.0005	0.0078	0.2500	0.0005	0.0082	0.1852	0.0005	0.0078	0.0877
*Mg	0.0789	1.1838		0.0837	1.3139		0.0711	1.1596		0.0738	1.1494	
Mn	0.0014	0.0213	0.0204	0.0011	0.0174	0.5550	0.0011	0.0171	0.3889	0.0016	0.0243	0.2737
Mo	0.0002	0.0028	0.0027	0.0001	0.0015	0.0465	0.0000	0.0006	0.0137	0.0001	0.0015	0.0167
Nd	0.0014	0.0212	0.0203	0.0002	0.0034	0.1075	0.0006	0.0090	0.2048	0.0020	0.0315	0.3544
Nickel	0.0003	0.0042	0.0040	0.0002	0.0037	0.1190	0.0002	0.0028	0.0641	0.0002	0.0037	0.0418
Pr	0.0000	0.0003	0.0003	0.0000	0.0003	0.0110	0.0000	0.0004	0.0085	0.0000	0.0004	0.0044
Ruthenium	0.0007	0.0099	0.0095	0.0002	0.0039	0.1230	0.0002	0.0038	0.0874	0.0007	0.0111	0.1254
Samarium	0.0010	0.0143	0.0138	0.0010	0.0152	0.4855	0.0009	0.0152	0.3452	0.0009	0.0144	0.1625
*Strontium	0.0113	0.1695		0.0111	0.1742		0.0101	0.1647		0.0105	0.1635	
Terbium	0.0000	0.0003	0.0003	0.0000	0.0002	0.0060	0.0000	0.0002	0.0052	0.0000	0.0004	0.0042
Titanium	0.0013	0.0194	0.0186	0.0012	0.0193	0.6150	0.0010	0.0162	0.3681	0.0011	0.0171	0.1930
*Zirconium	0.0087	0.1311		0.0067	0.1056		0.0061	0.0993		0.0090	0.1394	
*Others	0.1675	2.5129		0.1401	2.1986		0.1307	2.1317		0.1947	3.0316	
mg, Metals Found	6.6650	101.1043	3.3969	6.3705	101.1242	59.5050	6.1316	101.2356	46.0574	6.4208	101.1885	52.2088
mg, Filter Loading	6.9500			0.2000			0.2700			0.5700		

*High Al, Ba, B, Mg, Europium (?), Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A2.10C.44 Test 2/10C Marple M5 Elemental Analyses, Stages 4-7

2/10C	STAGE 4			STAGE 5			STAGE 6			STAGE 7		
M5	Particle size 6.0 µm			Particle size 3.5 µm			Particle size 1.55 µm			Particle size 0.93 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	1.3700	20.7571		1.2800	20.9700		1.5700	29.5924		1.5500	29.3484	
Antimony	0.0001	1.1364	0.0227	0.0001	1.2376	0.0124	0.0001	1.4620	0.0255	0.0001	1.4881	0.0962
*Barium	2.6500	40.1505		2.3500	38.4997		2.0500	38.6398		2.0700	39.1943	
*Boron	2.1800	33.0295		1.8900	30.9636		1.3100	24.6917		1.4900	28.2123	
Cerium	0.1030	1.5606	18.7273	0.1470	2.4083	14.5545	0.0448	0.8444	9.1429	0.0059	0.1117	4.5385
Cesium	0.0048	0.0727	0.8727	0.0143	0.2343	1.4158	0.0180	0.3393	3.6735	0.0071	0.1335	5.4231
Chromium	0.0013	0.0191	0.2291	0.0014	0.0226	0.1366	0.0015	0.0279	0.3020	0.0013	0.0248	1.0077
Copper	0.0728	1.1030	13.2364	0.1590	2.6049	15.7426	0.1480	2.7896	30.2041	0.0446	0.8445	34.3077
Europium	0.0013	0.0194	0.2327	0.0016	0.0254	0.1535	0.0007	0.0139	0.1506	0.0005	0.0097	0.3946
Iron	0.1130	1.7121	20.5455	0.1630	2.6704	16.1386	0.0749	1.4118	15.2857	0.0290	0.5491	22.3077
La	0.0001	0.0017	0.0198	0.0001	0.0017	0.0104	0.0001	0.0015	0.0159	0.0001	0.0016	0.0662
Lead	0.0006	0.0094	0.1124	0.0006	0.0095	0.0574	0.0005	0.0097	0.1055	0.0005	0.0095	0.3846
Lithium	0.0005	0.0076	0.0909	0.0005	0.0082	0.0495	0.0005	0.0094	0.1020	0.0005	0.0095	0.3846
*Mg	0.0761	1.1530		0.0669	1.0960		0.0602	1.1347		0.0628	1.1891	
Mn	0.0016	0.0244	0.2927	0.0021	0.0337	0.2040	0.0014	0.0254	0.2755	0.0008	0.0151	0.6131
Mo	0.0001	0.0016	0.0196	0.0003	0.0049	0.0298	0.0004	0.0082	0.0886	0.0002	0.0030	0.1238
Nd	0.0019	0.0285	0.3418	0.0024	0.0393	0.2376	0.0004	0.0076	0.0820	0.0002	0.0042	0.1723
Nickel	0.0003	0.0039	0.0467	0.0003	0.0054	0.0328	0.0003	0.0049	0.0533	0.0002	0.0030	0.1231
Pr	0.0000	0.0004	0.0047	0.0000	0.0004	0.0026	0.0000	0.0003	0.0037	0.0000	0.0004	0.0146
Ruthenium	0.0008	0.0122	0.1460	0.0019	0.0308	0.1861	0.0013	0.0239	0.2592	0.0004	0.0068	0.2754
Samarium	0.0009	0.0143	0.1715	0.0009	0.0143	0.0864	0.0006	0.0117	0.1265	0.0007	0.0131	0.5315
*Strontium	0.0110	0.1667		0.0101	0.1655		0.0086	0.1612		0.0084	0.1590	
Terbium	0.0000	0.0004	0.0045	0.0000	0.0006	0.0034	0.0000	0.0003	0.0029	0.0000	0.0002	0.0077
Titanium	0.0012	0.0176	0.2109	0.0012	0.0197	0.1188	0.0015	0.0275	0.2980	0.0011	0.0216	0.8769
*Zirconium	0.0088	0.1327		0.0103	0.1687		0.0117	0.2205		0.0070	0.1333	
*Others	0.1990	3.0151		0.2414	3.9542		0.1431	2.6972		0.0980	1.8563	
mg, Metals Found	6.6002	101.1345	55.3280	6.1039	101.2356	49.1728	5.3054	101.4596	60.1973	5.2814	101.4857	71.6492
mg, Filter Loading	0.5500			1.0100			0.4900			0.1300		

*High Al, Ba, B, Mg, Europium (?), Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A2.10C.45 Test 2/10C Marple M5 Elemental Analyses, Stages 8-9 & LPS L5

2/10C	STAGE 8			STAGE 9				LPS L5			
M5	Particle size 0.52 µm			Particle size final, <0.5 µm				S1: ~82-100 µm	S2: ~65-82 µm	S3: ~48-65 µm	S4: ~30-48 µm
	mg	% detect	% loading	mg	% detect	% loading		mg	mg	mg	mg
*Aluminum	1.2500	25.9893		1.5700	26.0047			0.8000	0.7440	0.8050	0.7800
Antimony	0.0001	1.6404	0.0417	0.0001	1.2994	0.1250		0.0001	0.0001	0.0001	0.0001
*Barium	1.8600	38.6720		2.4600	40.7462			1.1100	1.1000	1.1000	1.1100
*Boron	1.4500	30.1475		1.8100	29.9799			0.8310	0.8410	0.8260	0.7780
Cerium	0.0115	0.2391	3.8333	0.0056	0.0928	5.6000		0.0067	0.0091	0.0168	0.0799
Cesium	0.0197	0.4096	6.5667	0.0092	0.1516	9.1500		0.0002	0.0003	0.0003	0.0018
Chromium	0.0014	0.0285	0.4567	0.0012	0.0190	1.1500		0.0007	0.0008	0.0008	0.0009
Copper	0.1100	2.2871	36.6667	0.0513	0.8497	51.3000		0.0041	0.0053	0.0089	0.0637
Europium	0.0006	0.0117	0.1883	0.0006	0.0104	0.6300		0.0003	0.0003	0.0004	0.0010
Iron	0.0328	0.6820	10.9333	0.0297	0.4919	29.7000		0.0152	0.0157	0.0209	0.0881
La	0.0001	0.0018	0.0293	0.0001	0.0021	0.1270		0.0000	0.0000	0.0000	0.0001
Lead	0.0005	0.0099	0.1590	0.0007	0.0118	0.7140		0.0003	0.0003	0.0003	0.0005
Lithium	0.0005	0.0104	0.1667	0.0005	0.0083	0.5000		0.0005	0.0005	0.0005	0.0005
*Mg	0.0526	1.0936		0.0779	1.2903			0.0269	0.0276	0.0291	0.0307
Mn	0.0009	0.0179	0.2873	0.0009	0.0149	0.9000		0.0003	0.0003	0.0004	0.0011
Mo	0.0004	0.0084	0.1350	0.0002	0.0033	0.1980		0.0000	0.0000	0.0000	0.0001
Nd	0.0002	0.0035	0.0567	0.0002	0.0039	0.2380		0.0002	0.0001	0.0002	0.0013
Nickel	0.0002	0.0037	0.0587	0.0001	0.0021	0.1250		0.0001	0.0001	0.0001	0.0002
Pr	0.0000	0.0004	0.0063	0.0000	0.0005	0.0280		0.0000	0.0000	0.0000	0.0000
Ruthenium	0.0008	0.0171	0.2737	0.0004	0.0061	0.3690		0.0000	0.0000	0.0001	0.0004
Samarium	0.0007	0.0146	0.2337	0.0009	0.0147	0.8860		0.0004	0.0004	0.0004	0.0004
*Strontium	0.0076	0.1584		0.0096	0.1593			0.0051	0.0051	0.0051	0.0056
Terbium	0.0000	0.0002	0.0033	0.0000	0.0002	0.0100		0.0000	0.0000	0.0000	0.0000
Titanium	0.0006	0.0122	0.1963	0.0008	0.0126	0.7580		0.0005	0.0005	0.0005	0.0006
*Zirconium	0.0086	0.1784		0.0074	0.1217			0.0019	0.0016	0.0020	0.0057
*Others	0.0915	1.9015		0.1140	1.8881			0.0458	0.0469	0.0539	0.1254
mg, Metals Found	4.8097	101.6378	60.2927	6.0374	101.2973	102.5080		2.8048	2.7533	2.8180	2.9506
mg, Filter Loading	0.3000			0.1000							

*High Al, Ba, B, Mg, Europium (?), Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

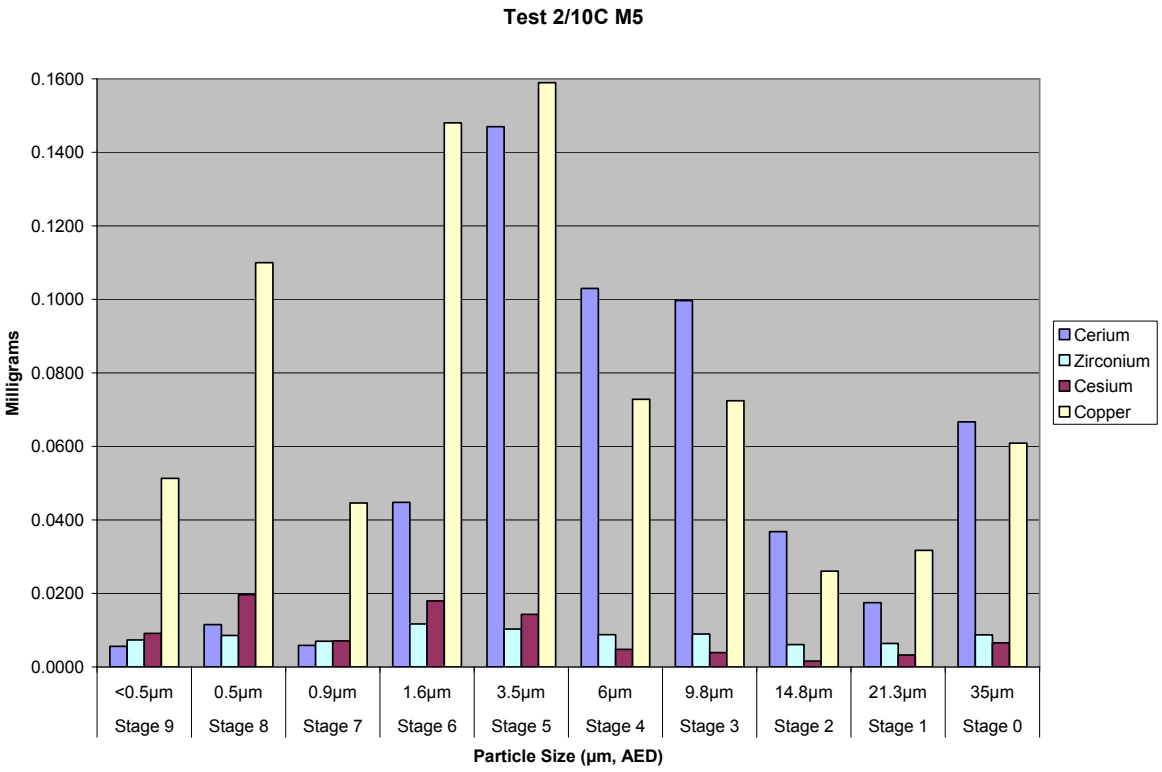


Figure A2.10C.50 Test 2/10C Marple M5 Metals Analysis Distribution, mg

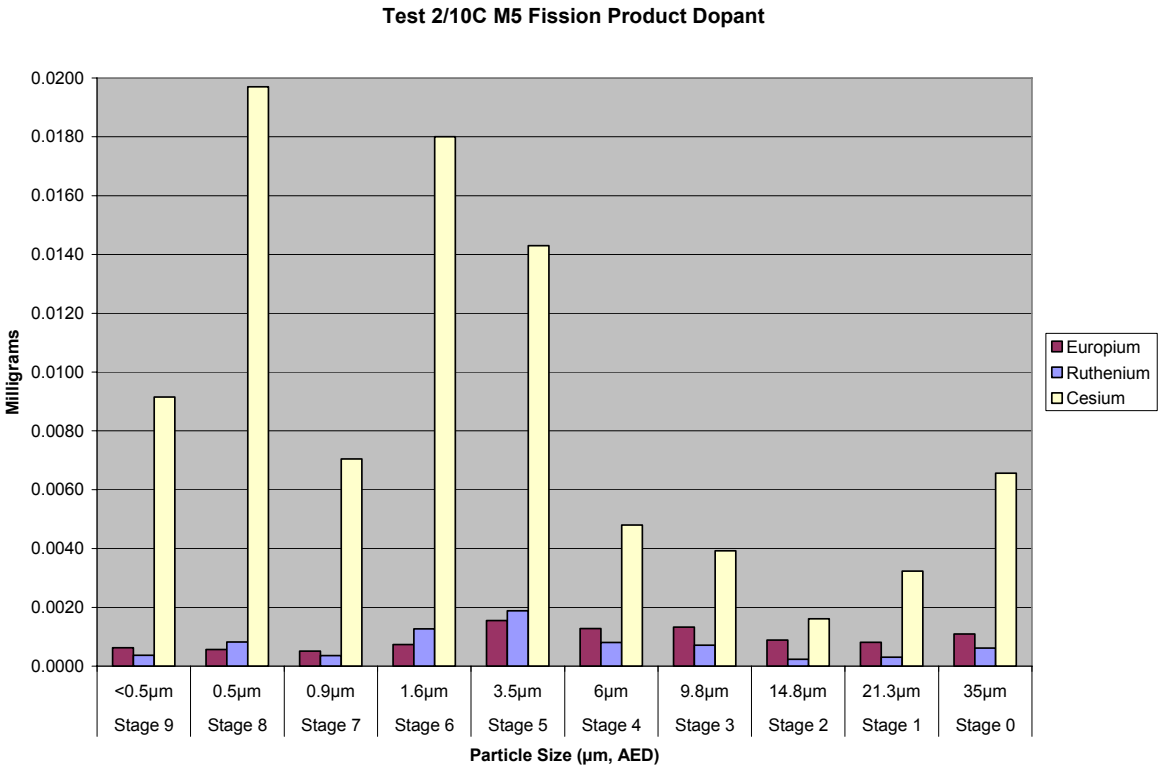


Figure A2.10C.51 Test 2/10C Marple M5 Fission Product Dopant Distribution, mg

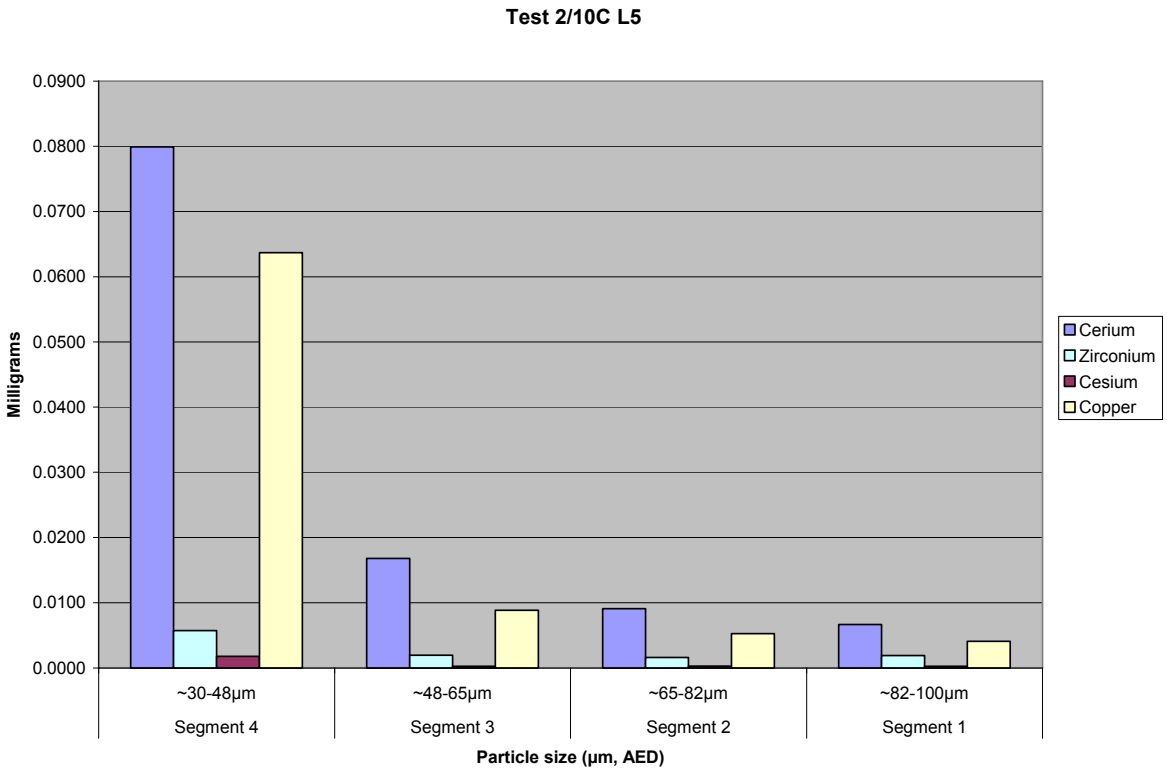


Figure A2.10C.52 Test 2/10C LPS L5 Metals Analysis Distribution, mg

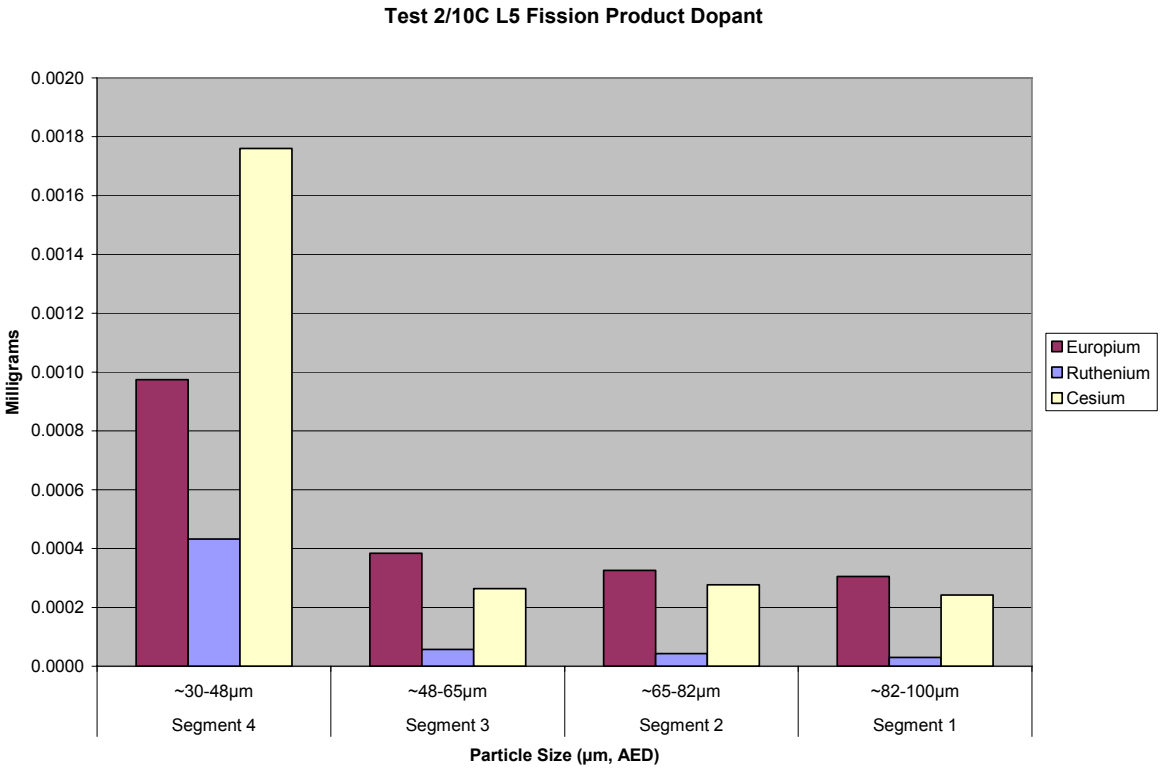


Figure A2.10C.53 Test 2/10C LPS L5 Fission Product Dopant Distribution, mg

Table A2.10C.46 Test 2/10C Marple M6 Elemental Analyses, Stages 0-3

2/10C	STAGE 0			STAGE 1			STAGE 2			STAGE 3		
M6	Particle size 35 µm			Particle size 21.3 µm			Particle size 14.8 µm			Particle size 9.8 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	1.6900	29.2969		1.7700	29.3210		1.7600	30.0841		1.7100	29.5371	
Antimony	0.0001	0.0022	0.0026	0.0001	0.0021	0.0313	0.0001	0.0021	0.0625	0.0001	0.0022	0.0250
*Barium	2.2200	38.4846		2.4300	40.2543		2.3400	39.9981		2.2900	39.5555	
*Boron	1.5400	26.6965		1.6200	26.8362		1.5700	26.8364		1.4700	25.3915	
Cerium	0.0643	1.1147	1.3396	0.0323	0.5351	8.0750	0.0243	0.4154	12.1500	0.0669	1.1556	13.3800
Cesium	0.0073	0.1259	0.1513	0.0036	0.0593	0.8950	0.0014	0.0231	0.6750	0.0027	0.0459	0.5320
Chromium	0.0014	0.0236	0.0283	0.0013	0.0215	0.3250	0.0012	0.0212	0.6200	0.0014	0.0240	0.2780
Copper	0.0725	1.2568	1.5104	0.0336	0.5566	8.4000	0.0193	0.3299	9.6500	0.0575	0.9932	11.5000
Europium	0.0009	0.0161	0.0193	0.0007	0.0118	0.1780	0.0006	0.0106	0.3100	0.0009	0.0154	0.1782
Iron	0.0760	1.3175	1.5833	0.0472	0.7819	11.8000	0.0406	0.6940	20.3000	0.0934	1.6133	18.6800
La	0.0001	0.0017	0.0021	0.0001	0.0016	0.0248	0.0001	0.0015	0.0440	0.0001	0.0014	0.0162
Lead	0.0005	0.0092	0.0111	0.0006	0.0093	0.1398	0.0005	0.0091	0.2660	0.0005	0.0093	0.1082
Lithium	0.0005	0.0087	0.0104	0.0005	0.0083	0.1250	0.0005	0.0085	0.2500	0.0005	0.0086	0.1000
*Mg	0.0705	1.2221		0.0749	1.2408		0.0722	1.2341		0.0713	1.2316	
Mn	0.0012	0.0211	0.0254	0.0010	0.0161	0.2425	0.0009	0.0151	0.4415	0.0014	0.0233	0.2700
Mo	0.0002	0.0029	0.0035	0.0001	0.0015	0.0225	0.0000	0.0006	0.0180	0.0001	0.0015	0.0172
Nd	0.0013	0.0227	0.0273	0.0004	0.0061	0.0918	0.0003	0.0053	0.1545	0.0013	0.0216	0.2500
Nickel	0.0002	0.0037	0.0045	0.0002	0.0027	0.0415	0.0001	0.0023	0.0680	0.0002	0.0035	0.0402
Pr	0.0000	0.0004	0.0005	0.0000	0.0004	0.0055	0.0000	0.0003	0.0100	0.0000	0.0003	0.0038
Ruthenium	0.0007	0.0119	0.0143	0.0003	0.0050	0.0750	0.0002	0.0026	0.0775	0.0004	0.0077	0.0894
Samarium	0.0007	0.0128	0.0154	0.0008	0.0130	0.1958	0.0007	0.0121	0.3530	0.0007	0.0112	0.1300
*Strontium	0.0092	0.1586		0.0099	0.1632		0.0094	0.1605		0.0096	0.1656	
Terbium	0.0000	0.0003	0.0004	0.0000	0.0002	0.0033	0.0000	0.0002	0.0055	0.0000	0.0003	0.0036
Titanium	0.0013	0.0224	0.0269	0.0013	0.0212	0.3200	0.0012	0.0202	0.5900	0.0012	0.0212	0.2460
*Zirconium	0.0096	0.1666		0.0079	0.1310		0.0066	0.1126		0.0092	0.1591	
*Others	0.1550	2.6876		0.1291	2.1384		0.1192	2.0373		0.1730	2.9888	
mg, Metals Found	5.7685	100.0000	4.7766	6.0366	100.0000	30.9915	5.8503	100.0000	46.0455	5.7893	100.0000	45.8478
mg, Filter Loading	4.8000			0.4000			0.2000			0.5000		

*High Al, Ba, B, Mg, Europium (?), Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A2.10C.47 Test 2/10C Marple M6 Elemental Analyses, Stages 4-7

2/10C	STAGE 4			STAGE 5			STAGE 6			STAGE 7		
M6	Particle size 6.0 µm			Particle size 3.5 µm			Particle size 1.55 µm			Particle size 0.93 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	1.8500	28.8912		1.7900	25.7706		1.7300	27.8124		1.2300	24.3978	
Antimony	0.0001	0.0020	0.0250	0.0001	0.0018	0.0139	0.0001	0.0020	0.1250	0.0001	0.0025	0.0026
*Barium	2.4700	38.5737		2.7100	39.0159		2.4400	39.2268		1.9100	37.8860	
*Boron	1.7600	27.4857		1.9500	28.0742		1.7600	28.2947		1.7300	34.3156	
Cerium	0.0723	1.1291	14.4600	0.1410	2.0300	15.6667	0.0402	0.6463	40.2000	0.0095	0.1876	
Cesium	0.0032	0.0500	0.6400	0.0088	0.1267	0.9778	0.0075	0.1211	7.5300	0.0079	0.1571	
Chromium	0.0014	0.0219	0.2800	0.0016	0.0225	0.1733	0.0015	0.0235	1.4600	0.0010	0.0200	
Copper	0.0546	0.8527	10.9200	0.1090	1.5693	12.1111	0.0732	1.1768	73.2000	0.0493	0.9779	
Europium	0.0009	0.0142	0.1816	0.0013	0.0180	0.1389	0.0007	0.0118	0.7320	0.0005	0.0107	
Iron	0.0883	1.3790	17.6600	0.1260	1.8140	14.0000	0.0641	1.0305	64.1000	0.0299	0.5931	
La	0.0001	0.0014	0.0184	0.0001	0.0015	0.0118	0.0001	0.0015	0.0930	0.0001	0.0017	
Lead	0.0006	0.0091	0.1162	0.0006	0.0088	0.0677	0.0006	0.0092	0.5720	0.0005	0.0090	
Lithium	0.0005	0.0078	0.1000	0.0005	0.0072	0.0556	0.0005	0.0080	0.5000	0.0005	0.0099	
*Mg	0.0772	1.2056		0.0758	1.0913		0.0766	1.2315		0.0568	1.1267	
Mn	0.0013	0.0209	0.2680	0.0017	0.0251	0.1933	0.0012	0.0195	1.2100	0.0008	0.0154	
Mo	0.0001	0.0014	0.0182	0.0002	0.0031	0.0237	0.0002	0.0030	0.1880	0.0002	0.0031	
Nd	0.0014	0.0222	0.2840	0.0023	0.0325	0.2511	0.0003	0.0048	0.2960	0.0001	0.0025	
Nickel	0.0002	0.0033	0.0426	0.0003	0.0038	0.0297	0.0002	0.0032	0.1970	0.0001	0.0026	
Pr	0.0000	0.0003	0.0044	0.0000	0.0004	0.0030	0.0000	0.0003	0.0210	0.0000	0.0004	
Ruthenium	0.0005	0.0078	0.1002	0.0012	0.0170	0.1311	0.0007	0.0111	0.6900	0.0005	0.0091	
Samarium	0.0007	0.0112	0.1440	0.0008	0.0117	0.0900	0.0007	0.0116	0.7240	0.0007	0.0142	
*Strontium	0.0102	0.1593		0.0110	0.1584		0.0099	0.1590		0.0076	0.1500	
Terbium	0.0000	0.0003	0.0040	0.0000	0.0005	0.0037	0.0000	0.0002	0.0140	0.0000	0.0002	
Titanium	0.0011	0.0176	0.2260	0.0015	0.0217	0.1678	0.0018	0.0289	1.8000	0.0007	0.0134	
*Zirconium	0.0085	0.1321		0.0121	0.1742		0.0101	0.1624		0.0047	0.0936	
*Others	0.1741	2.7183		0.2128	3.0638		0.1486	2.3895		0.0920	1.8253	
mg, Metals Found	6.4033	100.0000	45.4926	6.9459	100.0000	44.1100	6.2202	100.0000	193.6520	5.0414	100.0000	0.0026
mg, Filter Loading	0.5000			0.9000			0.1000			0.0000		

*High Al, Ba, B, Mg, Europium (?), Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A2.10C.48 Test 2/10C Marple M6 Elemental Analyses, Stages 8-9 & LPS L6

2/10C	STAGE 8			STAGE 9				LPS L6			
M6	Particle size 0.52 µm			Particle size final, <0.5 µm				S1: ~82-100 µm	S2: ~65-82 µm	S3: ~48-65 µm	S4: ~30-48 µm
	mg	% detect	% loading	mg	% detect	% loading		mg	mg	mg	mg
*Aluminum	1.3300	23.9828		1.9100	28.3589			0.7880	0.7050	0.7720	0.7880
Antimony	0.0001	0.0023	0.0026	0.0001	0.0019	0.0026		0.0001	0.0001	0.0000	0.0000
*Barium	2.1000	37.8676		2.6800	39.7916			1.1300	0.9600	1.0300	1.0100
*Boron	1.9000	34.2612		1.9300	28.6559			0.9640	0.8550	0.8690	0.8250
Cerium	0.0088	0.1589		0.0060	0.0895			0.0020	0.0012	0.0103	0.0257
Cesium	0.0143	0.2579		0.0101	0.1500			0.0001	0.0000	0.0002	0.0007
Chromium	0.0011	0.0206		0.0013	0.0192			0.0008	0.0007	0.0004	0.0005
Copper	0.0763	1.3759		0.0585	0.8686			0.0016	0.0010	0.0047	0.0166
Europium	0.0006	0.0114		0.0006	0.0085			0.0003	0.0002	0.0003	0.0004
Iron	0.0296	0.5338		0.0323	0.4796			0.0141	0.0099	0.0143	0.0314
La	0.0001	0.0019		0.0001	0.0016			0.0000	0.0000	0.0000	0.0000
Lead	0.0005	0.0092		0.0007	0.0109			0.0003	0.0003	0.0003	0.0003
Lithium	0.0005	0.0090		0.0005	0.0074			0.0005	0.0005	0.0001	0.0001
*Mg	0.0645	1.1631		0.0817	1.2131			0.0315	0.0263	0.0220	0.0249
Mn	0.0008	0.0148		0.0010	0.0143			0.0003	0.0003	0.0003	0.0005
Mo	0.0003	0.0053		0.0002	0.0035			0.0000	0.0000	0.0000	0.0000
Nd	0.0002	0.0030		0.0002	0.0031			0.0001	0.0001	0.0002	0.0004
Nickel	0.0002	0.0029		0.0001	0.0022			0.0001	0.0001	0.0001	0.0001
Pr	0.0000	0.0004		0.0000	0.0004			0.0000	0.0000	0.0000	0.0000
Ruthenium	0.0007	0.0120		0.0004	0.0062			0.0000	0.0000	0.0000	0.0001
Samarium	0.0008	0.0149		0.0008	0.0117			0.0004	0.0003	0.0003	0.0003
*Strontium	0.0082	0.1482		0.0100	0.1485			0.0051	0.0044	0.0045	0.0047
Terbium	0.0000	0.0002		0.0000	0.0001			0.0000	0.0000	0.0000	0.0000
Titanium	0.0006	0.0116		0.0010	0.0148			0.0005	0.0005	0.0003	0.0002
*Zirconium	0.0073	0.1313		0.0093	0.1385			0.0016	0.0010	0.0014	0.0021
*Others	0.1001	1.8042		0.1207	1.7923			0.0491	0.0394	0.0386	0.0594
mg, Metals Found	5.5456	100.0000	0.0026	6.7351	100.0000	0.0026		2.9414	2.5670	2.7307	2.7324
mg, Filter Loading	0.0000			0.0000							

*High Al, Ba, B, Mg, Europium (?), Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

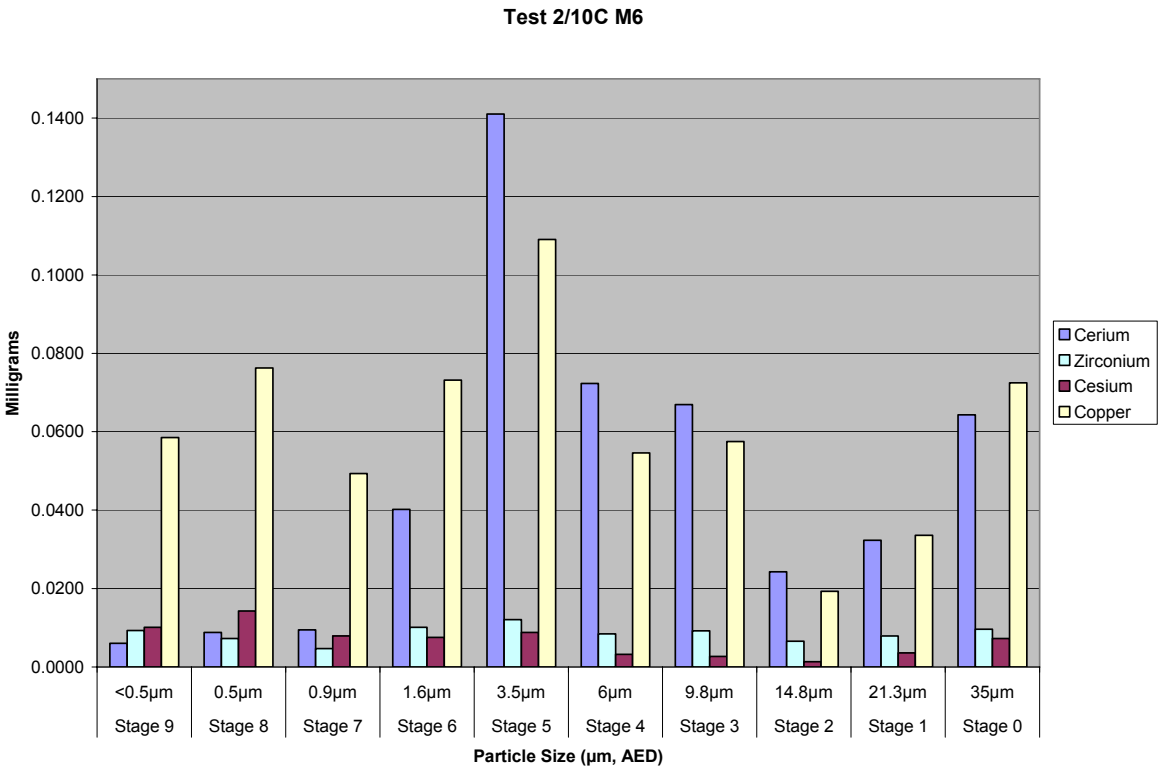


Figure A2.10C.54 Test 2/10C Marple M6 Metals Analysis Distribution, mg

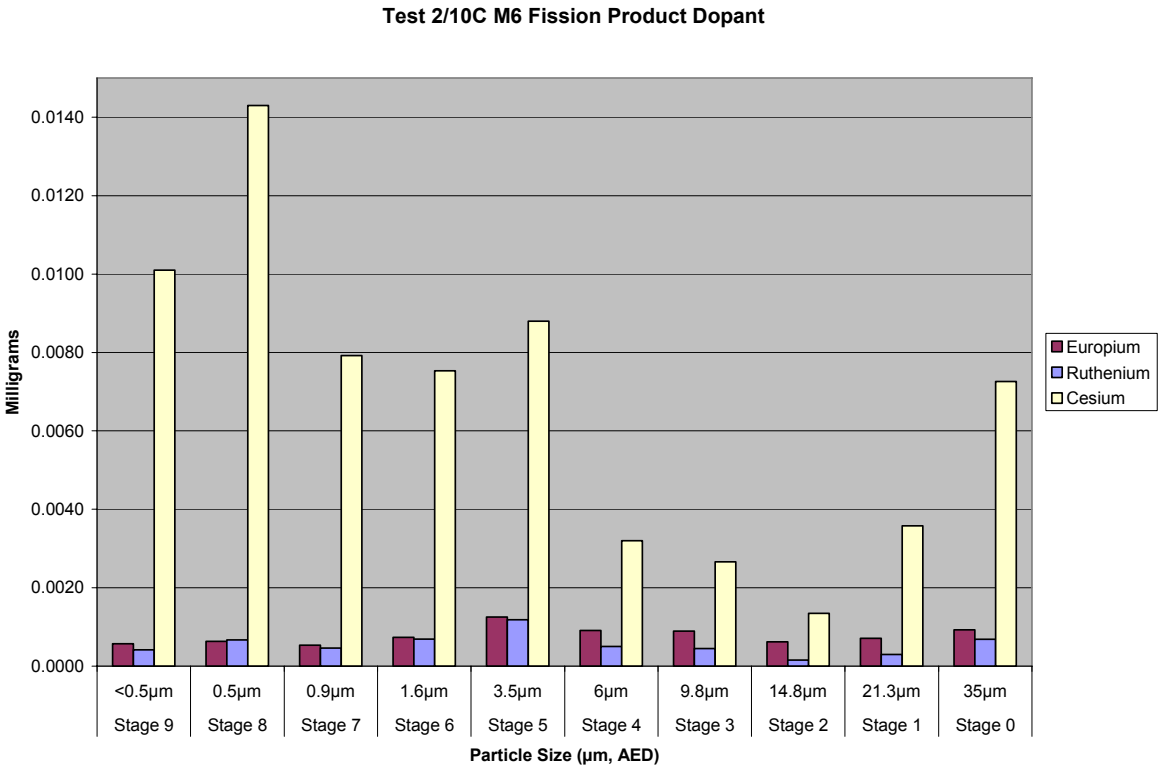


Figure A2.10C.55 Test 2/10C Marple M6 Fission Product Dopant Distribution, mg

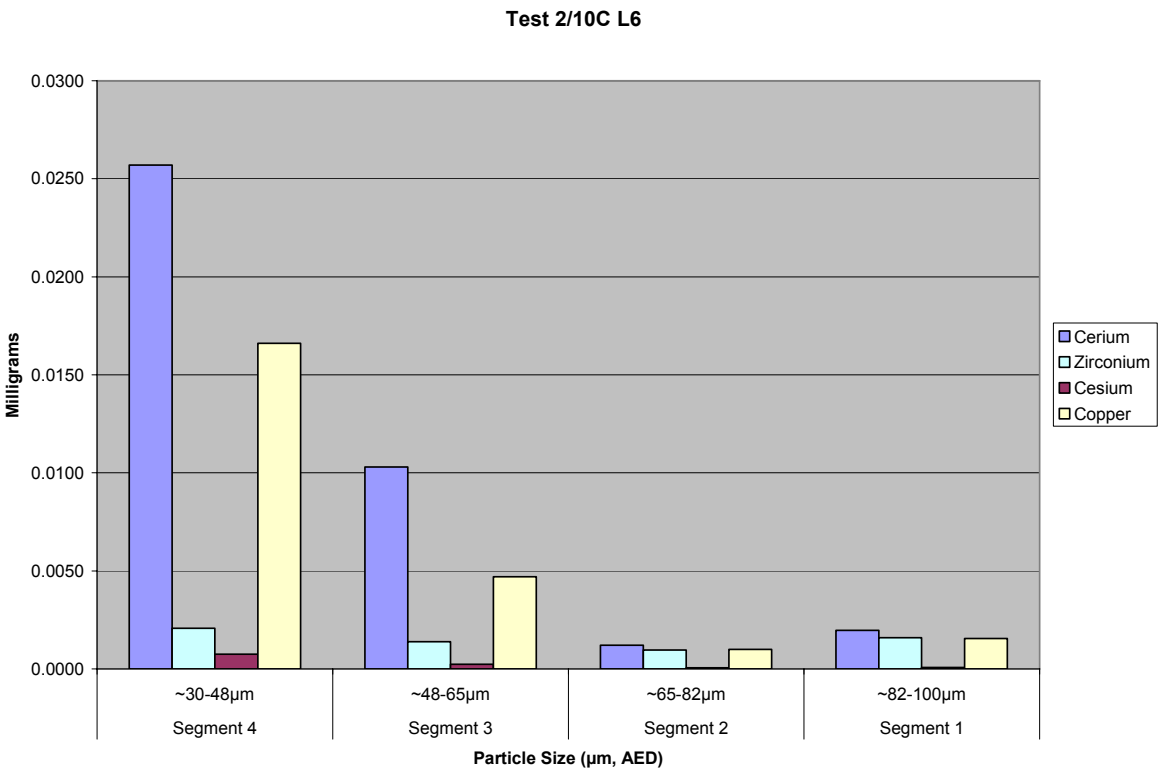


Figure A2.10C.56 Test 2/10C LPS L6 Metals Analysis Distribution, mg

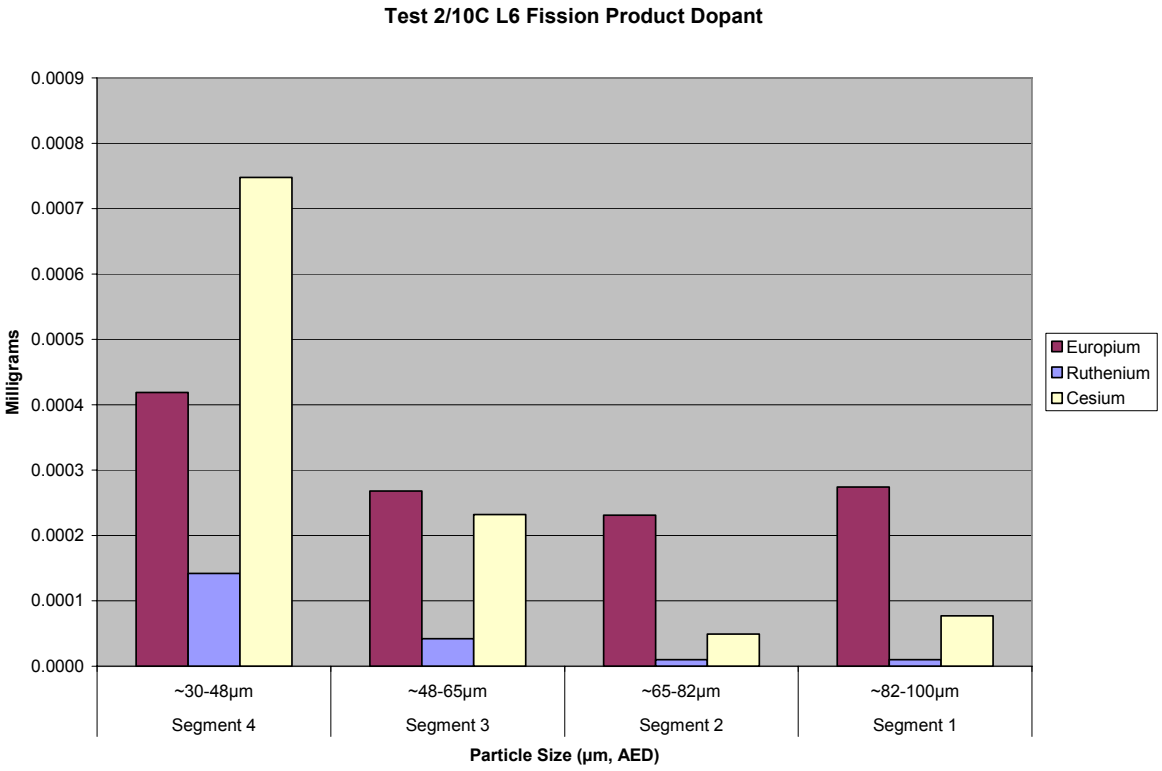


Figure A2.10C.57 Test 2/10C LPS L6 Fission Product Dopant Distribution, mg

A.2.10D Test 2/10D Analyses and Results

Particulates from test 2/10D, the replicate for test 2/10C, were sampled using four independent Large Particle Separator and Marple impactor systems. In addition, multiple separate impact particle debris samples were collected by a HEPA vacuum system and a newly installed pre-separator paper liner (collection bag). The impact particle debris was subsequently mechanically sieved and chemically analyzed by ICP-MS. Surface deposited particle samples were also obtained from the exterior and interior of each of the four internal chamber sampling tubes.

Gravimetric and Debris Analyses: Graphs of gravimetric particle size distributions from the four 2/10D Marple impactors, plus the mass concentrations, are presented in Figures A2.10D.58 to Figure A2.10C.62. The weight distribution of the sieved particle impact debris is presented in Table A2.10C.49. Table A2.10D.50 contains the measured impact debris elemental analysis, in weight percent, for the particles from 90 to < 25 μm (geometric) size, or 234 to <65 μm AED for CeO_2 pellets. The weight percent distribution of metals on the impact debris sieved fractions is plotted in Figure A2.10D.63 and Figure A2.10D.64 provides the similar impact debris weight percent distribution of fission product dopants.

Marple and LPS Particle Element Analyses: Chemical analyses were performed on three of the Marple and LPS particle collection systems, the fourth Marple and LPS samples were held in reserve. Each Large Particle Sampler fiberglass substrate was cut into four separate pieces prior to chemical dissolution and elemental analysis by ICP-MS. These LPS segments cover the nominal particle size range of: Segment #1 is ~82-100 μm AED, Segment #2 is ~65-82 μm AED, Segment #3 is ~48-65 μm AED, and Segment #4 is ~30-48 μm AED. The nomenclature for the Marple/LPS systems was somewhat modified for this test since alternate, identical apparatus was rotated into usage. The sampling system locations on top of the test chamber are labeled #1, #2, #3, and #4, as shown in Figure 4.7. However, the marked identifications on the Marples and LPS apparati connected to these locations were 003, 002, 005, and 006, respectively. In the tables and figures that follow for test 2/10D, location #1=M3 & L3, location #2=M2 & L2, location #3=M5 & L6, and location #4=M6 & L6, respectively.

All Marple M3 elemental analyses are listed in Tables A2.10D.51 to A2.10D.53 and are plotted in Figure A2.10D.65 for metals and Figure A2.10D.66 for fission product dopants. All LPS L3 elemental analyses are also listed in Table A2.10D.53 and are plotted in Figure A2.10D.67 for metals and Figure A2.10D.68 for fission product dopants.

All Marple M5 elemental analyses are listed in Tables A2.10D.54 to A2.10D.56 and are plotted in Figure A2.10D.69 for metals and Figure A2.10D.70 for fission product dopants. All LPS L5 elemental analyses are also listed in Table A2.10D.56 and are plotted in Figure A2.10D.71 for metals and Figure A2.10D.72 for fission product dopants.

All Marple M6 elemental analyses are listed in Tables A2.10D.57 to A2.10D.59 and are plotted in Figure A2.10D.73 for metals and Figure A2.10D.75 for fission product dopants. All LPS L6 elemental analyses are also listed in Table A2.10D.59 and are plotted in Figure A2.10D.75 for metals and Figure A2.10D.76 for fission product dopants.

NOTE: The final row “mg, Filter Loading” in tables that list the elemental analyses for Marple and LPS samples may be difficult to interpret. This is because the metal elements

content for aluminum, barium, magnesium, strontium, and zirconium have not been included. These elements were all present as significant impurities contained within the fiberglass substrates used, and not detected until later. So, the "corrected" values for "mg, Filter Loaging" are actually listed as lower in value than the analyzed "mg, metals found." The primary impact of this high impurity content in the fiberglass substrate is that measured values for "fission product content" for added dopant strontium has been masked. The strontium dopant content values are, therefore, unreliable and are not presented in the figures along with other measured fission product dopants.

Table A2.10D.49 Test 2/10D Weight Distribution of Impact Debris

Sieve #	Opening Size	AED Size for CeO_2	Weight, g Retained	Weight, g Passed	Percent Passed	Percent Retained
25	710 µm	1850 µm	19.486	4.11	17.411%	82.589%
35	500 µm	1300 µm	0.690	3.42	14.487%	85.513%
60	250 µm	650 µm	1.299	2.12	8.981%	91.019%
120	125 µm	325 µm	1.435	0.68	2.899%	97.101%
170	90 µm	234 µm	0.351	0.33	1.411%	98.589%
200	75 µm	193 µm	0.017	0.32	1.339%	98.661%
400	38 µm	99 µm	0.056	0.26	1.102%	98.898%
600	25 µm	65 µm	0.000	0.26	1.102%	98.898%
totals			23.334			

Table A2.10D.50 Test 2/10D Impact Debris Metals Weight Percent Distribution

Test 2/10D	90 µm	75 µm	38 µm	≤25 µm
Aluminum	0.01%	0.18%	0.20%	0.00%
Barium	0.00%	0.00%	0.00%	0.00%
Cerium	0.20%	18.73%	6.51%	0.00%
Cesium	0.03%	0.30%	0.54%	0.00%
Chromium	0.00%	0.03%	0.04%	0.00%
Copper	93.97%	21.71%	42.10%	0.00%
Europium	0.01%	0.16%	0.26%	0.00%
Iron	2.83%	28.31%	48.93%	0.00%
Lanthanum	0.00%	0.00%	0.00%	0.00%
Lead	0.00%	0.00%	0.00%	0.00%
Lithium	0.00%	0.00%	0.00%	0.00%
Magnesium	0.00%	0.06%	0.02%	0.00%
Manganese	0.03%	0.28%	0.40%	0.00%
Molybdenum	0.00%	0.01%	0.01%	0.00%
Neodymium	0.00%	0.35%	0.12%	0.00%
Nickel	0.00%	0.02%	0.04%	0.00%
Praseodymium	0.00%	0.00%	0.00%	0.00%
Ruthenium	0.01%	0.07%	0.12%	0.00%
Samarium	0.00%	0.00%	0.00%	0.00%
Strontium	0.01%	0.12%	0.23%	0.00%
Terbium	0.00%	0.00%	0.00%	0.00%
Titanium	0.00%	0.02%	0.03%	0.00%
Zirconium	0.00%	0.38%	0.43%	0.00%
*Others	2.88%	29.25%	49.86%	0.00%
Totals	100.00%	100.00%	100.00%	0.00%

*Sb, Ba, B, Cr, La, Pb, Li, Mg, Mn, Mo, Nd, Ni, Pr, Sm, Tb, Ti

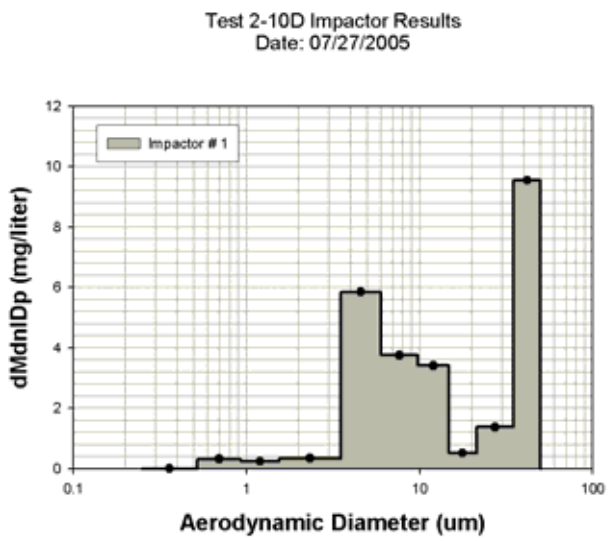


Figure A2.10D.58 Test 2/10D Marple #1 Size Distribution

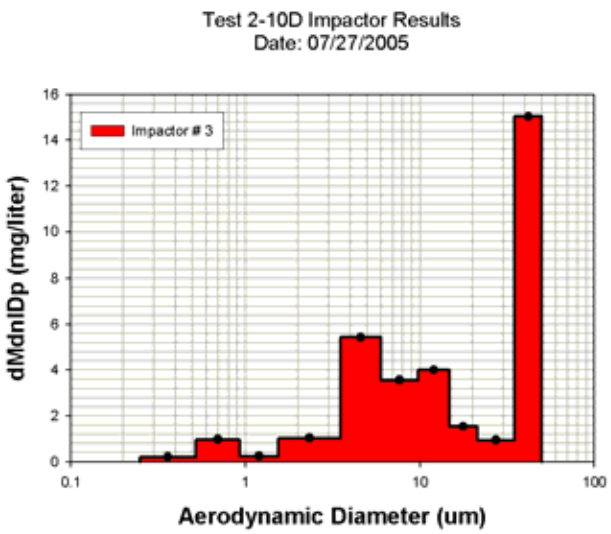


Figure A2.10D.60 Test 2/10D Marple #3 Size Distribution

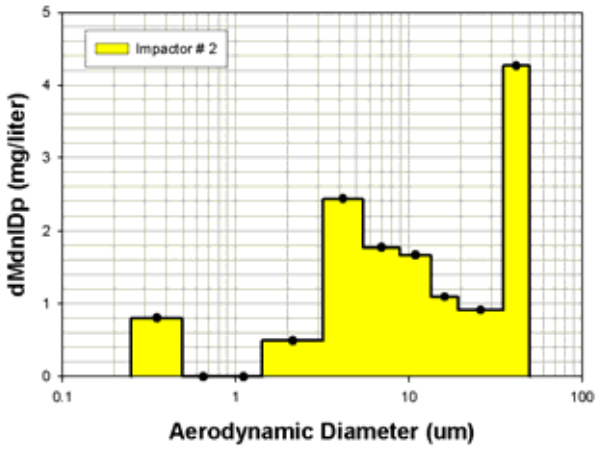


Figure A2.10D.59 Test 2/10D Marple #2 Size Distribution

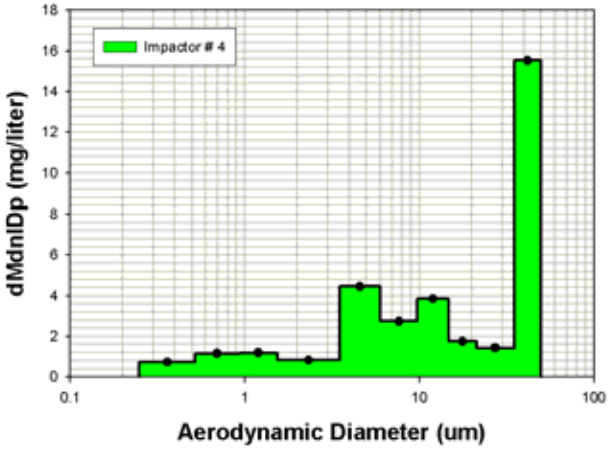


Figure A2.10D.61 Test 2/10D Marple #4 Size Distribution

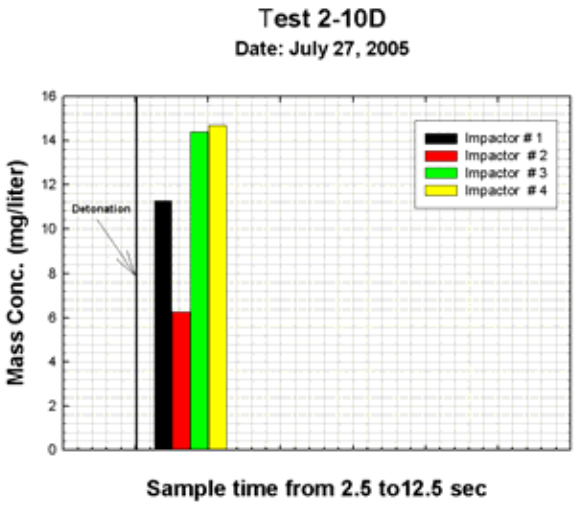


Figure A2.10C.62 Test 2/10D Marple Impactor Mass Concentration Data

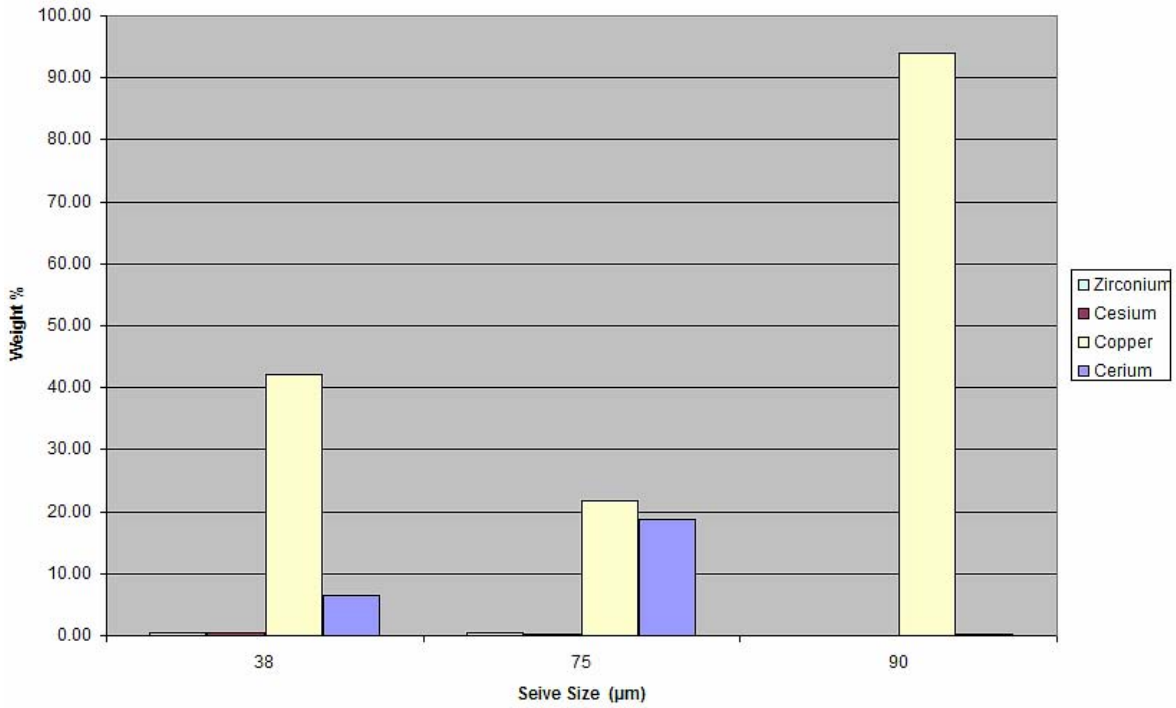


Figure A2.10D.63 Test 2/10D Metals Weight Percent Distribution, Impact Debris Fractions

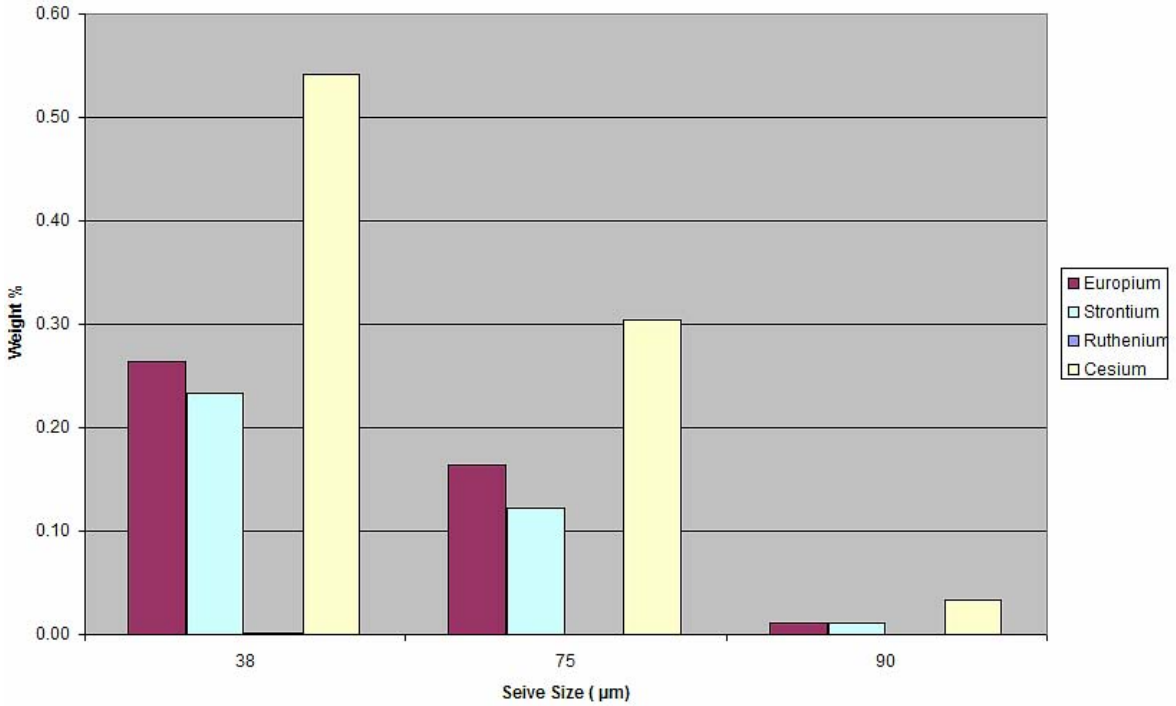


Figure A2.10D.64 Test 2/10D Fission Product Weight Percent Distribution, Impact Debris

Table A2.10D.51 Test 2/10D Marple M3 Elemental Analyses, Stages 0-3

2/10D	STAGE 0			STAGE 1			STAGE 2			STAGE 3		
M3	Particle size 35 µm			Particle size 21.3 µm			Particle size 14.8 µm			Particle size 9.8 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	1.3600	21.5946		1.3700	21.6221		1.3000	21.2851		1.3200	20.7552	
Antimony	0.0000	0.0005	0.0027	0.0000	0.0004	0.0127	0.0000	0.0004	0.0417	0.0000	0.0005	0.0069
*Barium	2.6100	41.4425		2.7000	42.6129		2.6000	42.5702		2.5400	39.9381	
*Boron	2.0100	31.9155		2.0700	32.6699		2.0200	33.0738		2.0800	32.7052	
Cerium	0.1070	1.6990	9.8165	0.0448	0.7071	20.3636	0.0488	0.7990	81.3333	0.1780	2.7988	39.5556
Cesium	0.0078	0.1231	0.7110	0.0029	0.0451	1.3000	0.0014	0.0232	2.3667	0.0039	0.0613	0.8667
Chromium	0.0008	0.0125	0.0724	0.0006	0.0099	0.2855	0.0006	0.0097	0.9850	0.0007	0.0110	0.1556
Copper	0.0559	0.8876	5.1284	0.0216	0.3409	9.8182	0.0178	0.2914	29.6667	0.0662	1.0409	14.7111
Europium	0.0010	0.0160	0.0927	0.0007	0.0114	0.3291	0.0007	0.0111	1.1300	0.0014	0.0219	0.3089
Iron	0.0521	0.8273	4.7798	0.0362	0.5713	16.4545	0.0356	0.5829	59.3333	0.0758	1.1919	16.8444
La	0.0001	0.0017	0.0097	0.0001	0.0016	0.0468	0.0001	0.0016	0.1617	0.0001	0.0017	0.0240
Lead	0.0006	0.0096	0.0553	0.0006	0.0097	0.2786	0.0006	0.0090	0.9183	0.0006	0.0096	0.1356
Lithium	0.0004	0.0061	0.0354	0.0004	0.0060	0.1736	0.0004	0.0059	0.6050	0.0004	0.0059	0.0840
*Mg	0.0654	1.0384		0.0661	1.0432		0.0614	1.0053		0.0651	1.0236	
Mn	0.0012	0.0191	0.1101	0.0010	0.0154	0.4441	0.0009	0.0151	1.5417	0.0013	0.0208	0.2933
Mo	0.0001	0.0013	0.0076	0.0000	0.0005	0.0155	0.0000	0.0003	0.0333	0.0000	0.0007	0.0098
Nd	0.0021	0.0333	0.1927	0.0011	0.0178	0.5136	0.0011	0.0178	1.8167	0.0009	0.0147	0.2080
Nickel	0.0002	0.0033	0.0191	0.0002	0.0029	0.0841	0.0002	0.0026	0.2633	0.0002	0.0031	0.0442
Pr	0.0000	0.0004	0.0024	0.0000	0.0003	0.0100	0.0000	0.0003	0.0350	0.0000	0.0004	0.0060
Ruthenium	0.0006	0.0097	0.0561	0.0003	0.0041	0.1173	0.0002	0.0031	0.3150	0.0006	0.0099	0.1402
Samarium	0.0007	0.0112	0.0645	0.0007	0.0110	0.3164	0.0006	0.0102	1.0400	0.0007	0.0106	0.1496
*Strontium	0.0099	0.1569		0.0102	0.1610		0.0094	0.1537		0.0104	0.1635	
Terbium	0.0000	0.0003	0.0016	0.0000	0.0002	0.0045	0.0000	0.0002	0.0167	0.0000	0.0003	0.0047
Titanium	0.0015	0.0235	0.1358	0.0012	0.0194	0.5591	0.0013	0.0210	2.1333	0.0014	0.0217	0.3067
*Zirconium	0.0105	0.1667		0.0073	0.1157		0.0065	0.1069		0.0120	0.1887	
Others	0.1262	2.0045		0.1091	1.7213		0.1034	1.6935		0.1487	2.3384	
mg, Metals Found	6.2979	100.0000	21.2938	6.3361	100.0000	51.1273	6.1076	100.0000	183.7367	6.3598	100.0000	73.8551
mg, Filter Loading	1.0900			0.2200			0.0600			0.4500		

*High Al, Ba, B, Mg, Europium (?), Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A2.10D.52 Test 2/10D Marple M3 Elemental Analyses, Stages 4-7

2/10D	STAGE 4			STAGE 5			STAGE 6			STAGE 7		
M3	Particle size 6.0 µm			Particle size 3.5 µm			Particle size 1.55 µm			Particle size 0.93 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	1.3300	20.6607		1.3700	20.6280		1.3100	21.9649		1.3200	21.9227	
Antimony	0.0000	0.0005	0.0051	0.0000	0.0005	0.0031	0.0000	0.0005	0.0322	0.0000	0.0004	0.0675
*Barium	2.5300	39.3020		2.5700	38.6964		2.4500	41.0793		2.5300	42.0184	
*Boron	2.1300	33.0882		2.0600	31.0173		1.9000	31.8574		2.0000	33.2161	
Cerium	0.1870	2.9049	31.6949	0.2630	3.9600	26.0396	0.0395	0.6623	43.8889	0.0082	0.1354	20.3750
Cesium	0.0049	0.0767	0.8373	0.0189	0.2846	1.8713	0.0207	0.3471	23.0000	0.0102	0.1694	25.5000
Chromium	0.0008	0.0118	0.1283	0.0009	0.0142	0.0936	0.0009	0.0155	1.0256	0.0007	0.0119	1.7925
Copper	0.0732	1.1371	12.4068	0.1390	2.0929	13.7624	0.0976	1.6365	108.4444	0.0341	0.5663	85.2500
Europium	0.0014	0.0222	0.2424	0.0018	0.0276	0.1812	0.0007	0.0116	0.7667	0.0005	0.0081	1.2150
Iron	0.0796	1.2365	13.4915	0.1080	1.6262	10.6931	0.0481	0.8065	53.4444	0.0269	0.4468	67.2500
La	0.0001	0.0016	0.0180	0.0001	0.0016	0.0107	0.0001	0.0017	0.1111	0.0001	0.0017	0.2525
Lead	0.0006	0.0097	0.1058	0.0006	0.0093	0.0609	0.0006	0.0101	0.6689	0.0006	0.0099	1.4900
Lithium	0.0004	0.0061	0.0666	0.0004	0.0056	0.0370	0.0004	0.0062	0.4078	0.0004	0.0061	0.9150
*Mg	0.0678	1.0532		0.0695	1.0465		0.0677	1.1351		0.0675	1.1210	
Mn	0.0014	0.0221	0.2407	0.0017	0.0259	0.1703	0.0012	0.0200	1.3222	0.0009	0.0150	2.2550
Mo	0.0001	0.0008	0.0085	0.0001	0.0022	0.0145	0.0002	0.0030	0.2000	0.0001	0.0015	0.2275
Nd	0.0041	0.0643	0.7017	0.0067	0.1006	0.6614	0.0003	0.0047	0.3144	0.0001	0.0022	0.3300
Nickel	0.0002	0.0031	0.0337	0.0003	0.0038	0.0252	0.0002	0.0029	0.1933	0.0001	0.0021	0.3150
Pr	0.0000	0.0004	0.0044	0.0000	0.0004	0.0029	0.0000	0.0004	0.0233	0.0000	0.0003	0.0500
Ruthenium	0.0008	0.0117	0.1280	0.0016	0.0245	0.1614	0.0011	0.0186	1.2333	0.0005	0.0079	1.1850
Samarium	0.0007	0.0103	0.1122	0.0007	0.0101	0.0663	0.0006	0.0106	0.7011	0.0006	0.0105	1.5750
*Strontium	0.0109	0.1693		0.0109	0.1641		0.0096	0.1608		0.0095	0.1576	
Terbium	0.0000	0.0003	0.0037	0.0000	0.0004	0.0028	0.0000	0.0002	0.0111	0.0000	0.0002	0.0250
Titanium	0.0013	0.0199	0.2169	0.0012	0.0179	0.1178	0.0012	0.0196	1.3000	0.0012	0.0198	2.9750
*Zirconium	0.0120	0.1864		0.0159	0.2394		0.0134	0.2247		0.0090	0.1488	
Others	0.1585	2.4628		0.1921	2.8928		0.1222	2.0484		0.0998	1.6574	
mg, Metals Found	6.4373	100.0000	60.4464	6.6415	100.0000	53.9753	5.9641	100.0000	237.0889	6.0212	100.0000	213.0450
mg, Filter Loading	0.5900			1.0100			0.0900			0.0400		

*High Al, Ba, B, Mg, Europium (?), Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A2.10D.53 Test 2/10D Marple M3 Elemental Analyses, Stages 8-9 & LPS L3

2/10D	STAGE 8			STAGE 9				LPS L3			
M3	Particle size 0.52 µm			Particle size final, <0.5 µm				S1: ~82-100 µm	S2: ~65-82 µm	S3: ~48-65 µm	S4: ~30-48 µm
	mg	% detect	% loading	mg	% detect	% loading		mg	mg	mg	mg
*Aluminum	1.3500	22.0448		1.4900	22.3870			0.3900	0.3900	0.4150	0.4300
Antimony	0.0000	0.0005	0.0483	0.0000	0.0005	0.0030		0.0000	0.0000	0.0000	0.0000
*Barium	2.5300	41.3136		2.8400	42.6706			0.6050	0.6220	0.6490	0.6840
*Boron	2.0200	32.9855		2.1800	32.7542			0.4230	1.1500	1.1800	1.2400
Cerium	0.0096	0.1564	15.9667	0.0012	0.0180			0.0129	0.0059	0.0330	0.1970
Cesium	0.0191	0.3119	31.8333	0.0019	0.0278			0.0004	0.0001	0.0005	0.0023
Chromium	0.0009	0.0144	1.4683	0.0006	0.0097			0.0003	0.0002	0.0003	0.0004
Copper	0.0694	1.1333	115.6667	0.0071	0.1061			0.0056	0.0022	0.0107	0.0687
Europium	0.0005	0.0082	0.8417	0.0005	0.0073			0.0002	0.0001	0.0003	0.0013
Iron	0.0304	0.4964	50.6667	0.0232	0.3486			0.0135	0.0080	0.0173	0.0699
La	0.0001	0.0017	0.1700	0.0001	0.0019			0.0000	0.0000	0.0000	0.0000
Lead	0.0006	0.0101	1.0300	0.0008	0.0121			0.0002	0.0002	0.0002	0.0002
Lithium	0.0004	0.0061	0.6200	0.0004	0.0067			0.0001	0.0001	0.0001	0.0001
*Mg	0.0652	1.0647		0.0891	1.3387			0.0798	0.0776	0.0684	0.0698
Mn	0.0010	0.0160	1.6350	0.0015	0.0227			0.0003	0.0002	0.0003	0.0008
Mo	0.0002	0.0027	0.2733	0.0000	0.0004			0.0000	0.0000	0.0000	0.0000
Nd	0.0001	0.0013	0.1350	0.0001	0.0019			0.0003	0.0001	0.0003	0.0046
Nickel	0.0002	0.0025	0.2533	0.0001	0.0017			0.0001	0.0000	0.0000	0.0001
Pr	0.0000	0.0003	0.0333	0.0000	0.0004			0.0000	0.0000	0.0000	0.0000
Ruthenium	0.0008	0.0129	1.3183	0.0001	0.0012			0.0001	0.0000	0.0001	0.0005
Samarium	0.0006	0.0103	1.0533	0.0007	0.0105			0.0001	0.0001	0.0002	0.0002
*Strontium	0.0099	0.1610		0.0108	0.1623			0.0026	0.0026	0.0027	0.0034
Terbium	0.0000	0.0002	0.0167	0.0000	0.0002			0.0000	0.0000	0.0000	0.0000
Titanium	0.0014	0.0232	2.3667	0.0013	0.0194			0.0005	0.0004	0.0005	0.0005
*Zirconium	0.0136	0.2221		0.0060	0.0903			0.0018	0.0014	0.0024	0.0072
Others	0.1016	1.6585		0.1186	1.7825			0.0954	0.0873	0.0879	0.1480
mg, Metals Found	6.1239	100.0000	225.3967	6.6556	100.0000	0.0030		1.5367	2.2616	2.3813	2.7812
mg, Filter Loading	0.0600			0.0000							

*High Al, Ba, B, Mg, Europium (?), Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

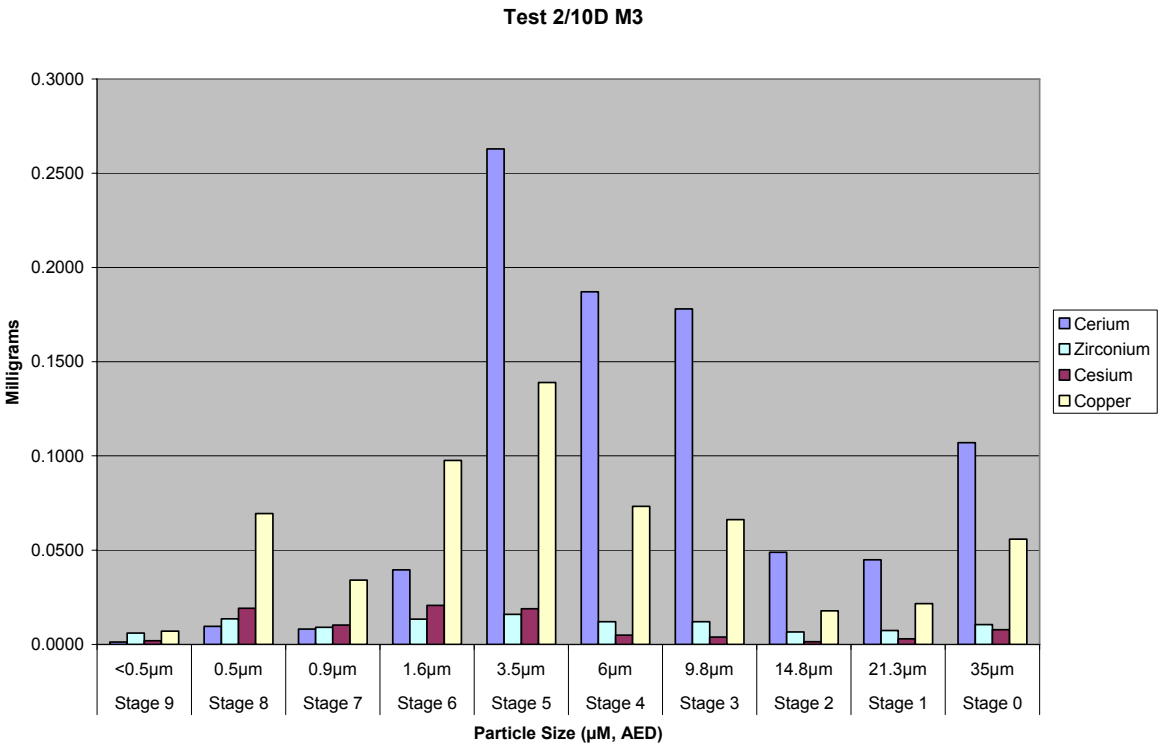


Figure A2.10D.65 Test 2/10D Marple M3 Metals Analysis Distribution, mg

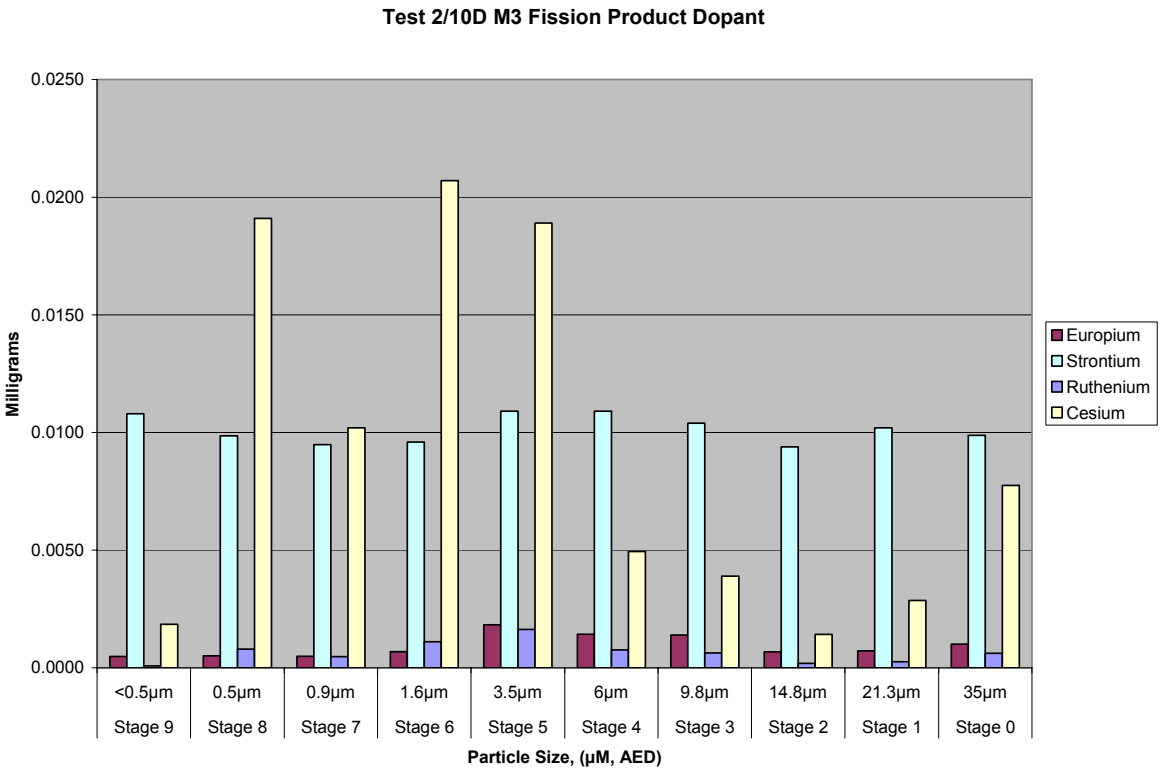


Figure A2.10D.66 Test 2/10D Marple M3 Fission Product Dopant Distribution, mg

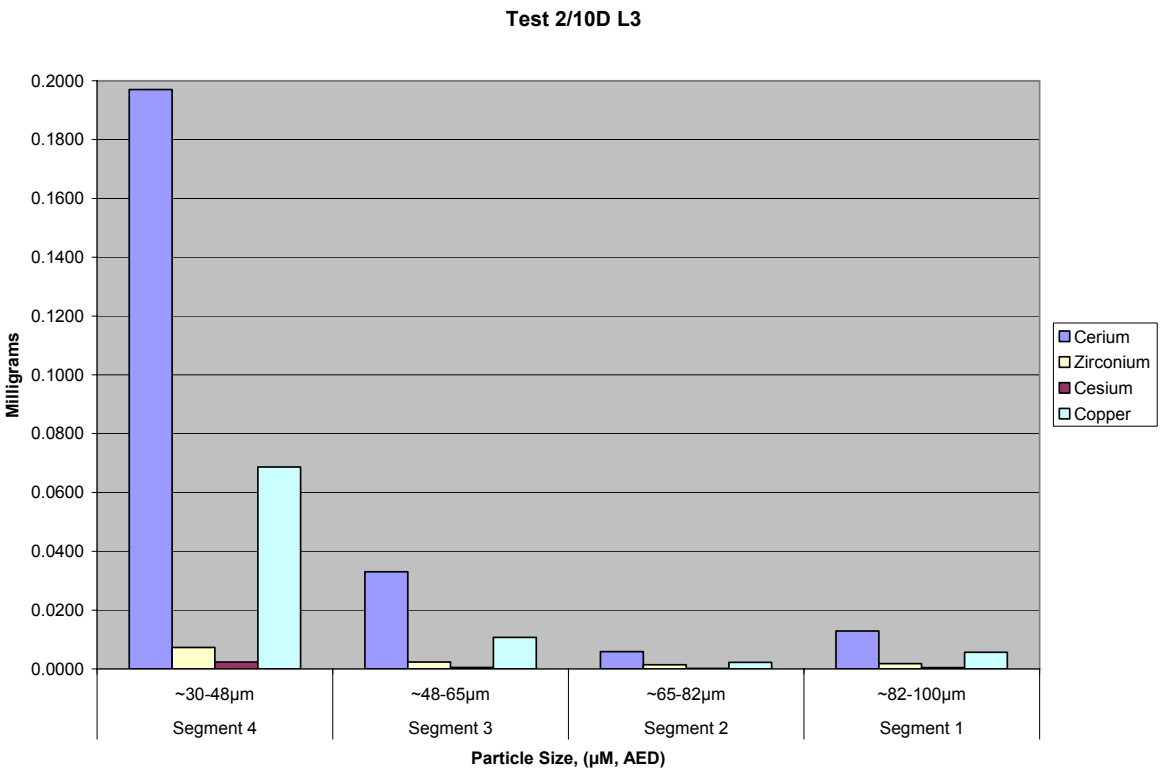


Figure A2.10D.67 Test 2/10D LPS L3 Metals Analysis Distribution, mg

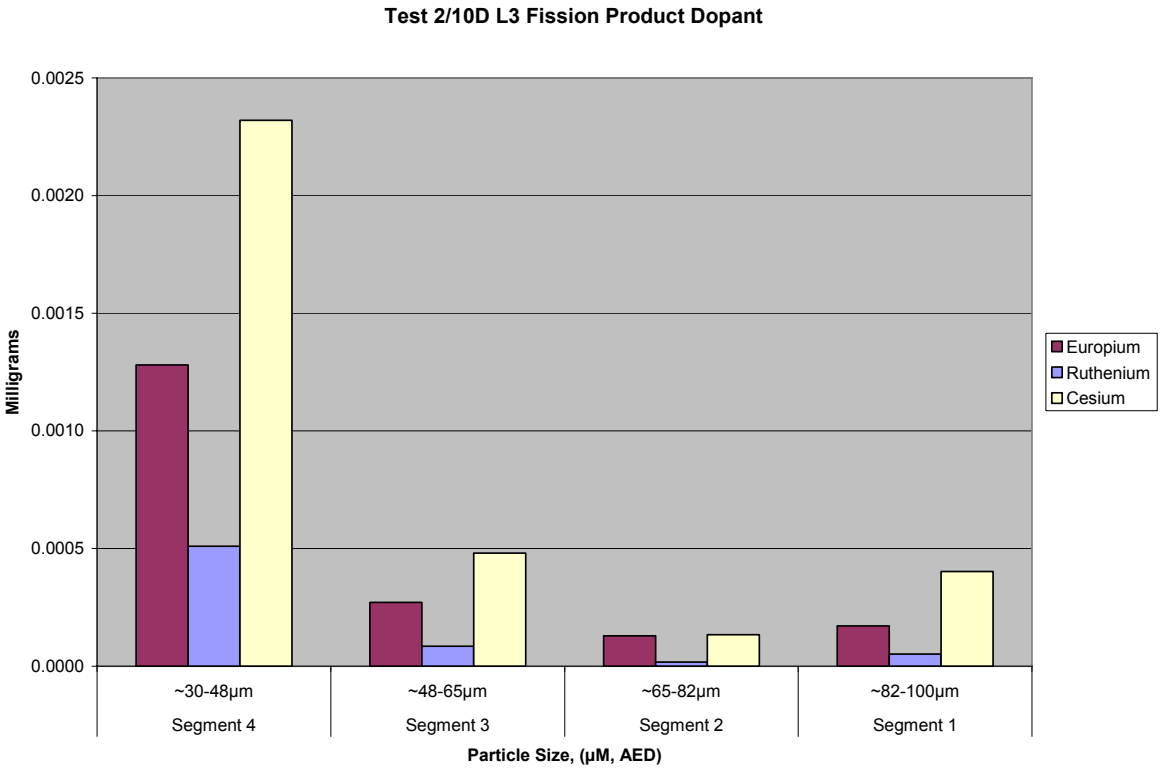


Figure A2.10D.68 Test 2/10D LPS L3 Fission Product Dopant Distribution, mg

Table A2.10D.54 Test 2/10D Marple M5 Elemental Analyses, Stages 0-3

2/10D	STAGE 0			STAGE 1			STAGE 2			STAGE 3		
M5	Particle size 35 µm			Particle size 21.3 µm			Particle size 14.8 µm			Particle size 9.8 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	1.3300	21.8481		1.2500	21.6695		1.3300	21.8440		1.2700	20.5096	
Antimony	0.0000	0.0005	0.0017	0.0000	0.0005	0.0193	0.0000	0.0005	0.0156	0.0000	0.0004	0.0051
*Barium	2.4800	40.7393		2.4300	42.1255		2.5600	42.0457		2.5600	41.3422	
*Boron	1.9100	31.3759		1.8600	32.2442		1.9900	32.6839		1.9300	31.1681	
Cerium	0.1270	2.0862	7.3837	0.0654	1.1337	43.6000	0.0562	0.9230	31.2222	0.1900	3.0684	35.8491
Cesium	0.0087	0.1426	0.5047	0.0035	0.0608	2.3400	0.0018	0.0296	1.0000	0.0040	0.0646	0.7547
Chromium	0.0008	0.0125	0.0444	0.0006	0.0109	0.4200	0.0006	0.0104	0.3522	0.0007	0.0105	0.1228
Copper	0.0687	1.1285	3.9942	0.0279	0.4837	18.6000	0.0207	0.3400	11.5000	0.0650	1.0497	12.2642
Europium	0.0012	0.0189	0.0669	0.0008	0.0139	0.5340	0.0008	0.0127	0.4283	0.0014	0.0228	0.2660
Iron	0.0633	1.0398	3.6802	0.0408	0.7073	27.2000	0.0376	0.6175	20.8889	0.0788	1.2726	14.8679
La	0.0001	0.0018	0.0062	0.0001	0.0018	0.0680	0.0001	0.0018	0.0606	0.0001	0.0017	0.0196
Lead	0.0006	0.0098	0.0348	0.0006	0.0102	0.3907	0.0006	0.0099	0.3361	0.0006	0.0095	0.1113
Lithium	0.0004	0.0060	0.0214	0.0004	0.0062	0.2380	0.0004	0.0062	0.2111	0.0003	0.0056	0.0653
*Mg	0.0682	1.1203		0.0662	1.1476		0.0674	1.1070		0.0619	0.9996	
Mn	0.0015	0.0238	0.0843	0.0010	0.0171	0.6593	0.0010	0.0159	0.5367	0.0013	0.0207	0.2415
Mo	0.0001	0.0014	0.0048	0.0000	0.0006	0.0220	0.0000	0.0004	0.0133	0.0000	0.0007	0.0081
Nd	0.0027	0.0435	0.1541	0.0017	0.0290	1.1133	0.0013	0.0210	0.7111	0.0041	0.0661	0.7717
Nickel	0.0002	0.0034	0.0119	0.0002	0.0026	0.1013	0.0001	0.0021	0.0711	0.0002	0.0032	0.0374
Pr	0.0000	0.0004	0.0015	0.0000	0.0004	0.0147	0.0000	0.0004	0.0128	0.0000	0.0004	0.0047
Ruthenium	0.0007	0.0120	0.0426	0.0003	0.0056	0.2160	0.0002	0.0037	0.1267	0.0007	0.0107	0.1255
Samarium	0.0007	0.0107	0.0380	0.0006	0.0110	0.4213	0.0007	0.0109	0.3678	0.0007	0.0106	0.1234
*Strontium	0.0101	0.1659		0.0094	0.1636		0.0102	0.1675		0.0103	0.1663	
Terbium	0.0000	0.0003	0.0010	0.0000	0.0002	0.0073	0.0000	0.0002	0.0061	0.0000	0.0003	0.0038
Titanium	0.0013	0.0209	0.0738	0.0012	0.0205	0.7867	0.0013	0.0220	0.7444	0.0011	0.0181	0.2113
*Zirconium	0.0114	0.1873		0.0077	0.1337		0.0075	0.1237		0.0110	0.1776	
*Others	0.1409	2.3141		0.1142	1.9796		0.1120	1.8389		0.1513	2.4427	
mg, Metals Found	6.0875	100.0000	16.1501	5.7685	100.0000	96.7520	6.0886	100.0000	68.6050	6.1922	100.0000	65.8534
mg, Filter Loading	1.7200			0.1500			0.1800			0.5300		

*High Al, Ba, B, Mg, Europium (?), Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A2.10D.55 Test 2/10D Marple M5 Elemental Analyses, Stages 4-7

2/10D	STAGE 4			STAGE 5			STAGE 6			STAGE 7		
M5	Particle size 6.0 µm			Particle size 3.5 µm			Particle size 1.55 µm			Particle size 0.93 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	1.3100	20.7269		1.3200	20.1913		1.1800	22.4190		1.7800	23.0266	
Antimony	0.0000	0.0004	0.0048	0.0000	0.0005	0.0032	0.0000	0.0006	0.0115	0.0000	0.0005	0.0975
*Barium	2.6200	41.4539		2.5400	38.8530		2.1500	40.8482		3.2600	42.1723	
*Boron	2.0000	31.6442		2.0200	30.8989		1.7300	32.8686		2.5300	32.7288	
Cerium	0.1570	2.4841	28.0357	0.2600	3.9771	27.6596	0.0264	0.5016	9.7778	0.0038	0.0493	9.5250
Cesium	0.0051	0.0801	0.9036	0.0219	0.3350	2.3298	0.0174	0.3306	6.4444	0.0049	0.0639	12.3500
Chromium	0.0007	0.0111	0.1254	0.0010	0.0149	0.1033	0.0007	0.0137	0.2667	0.0007	0.0090	1.7325
Copper	0.0613	0.9699	10.9464	0.1490	2.2792	15.8511	0.0565	1.0735	20.9259	0.0143	0.1850	35.7500
Europium	0.0013	0.0209	0.2357	0.0020	0.0300	0.2085	0.0006	0.0109	0.2122	0.0006	0.0079	1.5200
Iron	0.0707	1.1186	12.6250	0.1150	1.7591	12.2340	0.0345	0.6555	12.7778	0.0279	0.3609	69.7500
La	0.0001	0.0017	0.0193	0.0001	0.0018	0.0122	0.0001	0.0017	0.0326	0.0001	0.0017	0.3200
Lead	0.0006	0.0095	0.1071	0.0006	0.0095	0.0659	0.0005	0.0091	0.1767	0.0007	0.0096	1.8525
Lithium	0.0004	0.0059	0.0661	0.0004	0.0056	0.0389	0.0003	0.0049	0.0952	0.0004	0.0050	0.9750
*Mg	0.0635	1.0047		0.0684	1.0463		0.0450	0.8550		0.0852	1.1022	
Mn	0.0013	0.0199	0.2250	0.0018	0.0269	0.1872	0.0008	0.0160	0.3119	0.0010	0.0125	2.4125
Mo	0.0000	0.0007	0.0080	0.0002	0.0027	0.0190	0.0001	0.0028	0.0541	0.0001	0.0006	0.1250
Nd	0.0039	0.0612	0.6911	0.0056	0.0860	0.5979	0.0001	0.0016	0.0311	0.0001	0.0019	0.3625
Nickel	0.0003	0.0040	0.0454	0.0003	0.0041	0.0288	0.0001	0.0025	0.0496	0.0001	0.0016	0.3050
Pr	0.0000	0.0004	0.0046	0.0000	0.0005	0.0033	0.0000	0.0004	0.0070	0.0000	0.0003	0.0625
Ruthenium	0.0007	0.0107	0.1204	0.0019	0.0288	0.2000	0.0008	0.0147	0.2870	0.0002	0.0024	0.4600
Samarium	0.0006	0.0102	0.1150	0.0007	0.0102	0.0711	0.0006	0.0109	0.2119	0.0009	0.0112	2.1625
*Strontium	0.0105	0.1661		0.0106	0.1621		0.0078	0.1482		0.0121	0.1565	
Terbium	0.0000	0.0003	0.0036	0.0000	0.0004	0.0031	0.0000	0.0002	0.0037	0.0000	0.0001	0.0250
Titanium	0.0014	0.0222	0.2500	0.0013	0.0193	0.1340	0.0011	0.0201	0.3926	0.0011	0.0138	2.6750
*Zirconium	0.0109	0.1725		0.0168	0.2570		0.0100	0.1900		0.0059	0.0765	
*Others	0.1448	2.2918		0.1973	3.0177		0.0845	1.6057		0.1190	1.5388	
mg, Metals Found	6.3203	100.0000	54.5321	6.5375	100.0000	59.7510	5.2634	100.0000	52.0696	7.7302	100.0000	142.4625
mg, Filter Loading	0.5600			0.9400			0.2700			0.0400		

*High Al, Ba, B, Mg, Europium (?), Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A2.10D.56 Test 2/10D Marple M5 Elemental Analyses, Stages 8-9 & LPS L5

2/10D	STAGE 8			STAGE 9				LPS L5			
M5	Particle size 0.52 µm			Particle size final, <0.5 µm				S1: ~82-100 µm	S2: ~65-82 µm	S3: ~48-65 µm	S4: ~30-48 µm
	mg	% detect	% loading	mg	% detect	% loading		mg	mg	mg	mg
*Aluminum	1.0700	23.4324		1.1500	23.3660			0.3880	0.3860	0.3930	0.3720
Antimony	0.0000	0.0005	0.0139	0.0000	0.0005	0.0520		0.0000	0.0000	0.0000	0.0000
*Barium	1.8100	39.6379		2.0600	41.8555			0.5430	0.5270	0.5440	0.5300
*Boron	1.5400	33.7251		1.5800	32.1028			0.4480	0.4440	0.4620	0.4420
Cerium	0.0068	0.1489	3.7778	0.0039	0.0784	7.7200		0.0213	0.0164	0.0145	0.0320
Cesium	0.0148	0.3241	8.2222	0.0074	0.1493	14.7000		0.0004	0.0002	0.0002	0.0003
Chromium	0.0007	0.0144	0.3661	0.0006	0.0117	1.1480		0.0013	0.0009	0.0003	0.0007
Copper	0.0396	0.8672	22.0000	0.0204	0.4145	40.8000		0.0070	0.0050	0.0040	0.0087
Europium	0.0004	0.0085	0.2167	0.0004	0.0078	0.7640		0.0002	0.0002	0.0002	0.0003
Iron	0.0226	0.4949	12.5556	0.0214	0.4348	42.8000		0.0162	0.0127	0.0097	0.0158
La	0.0001	0.0017	0.0428	0.0001	0.0019	0.1880		0.0000	0.0000	0.0000	0.0000
Lead	0.0004	0.0093	0.2367	0.0006	0.0114	1.1180		0.0002	0.0002	0.0002	0.0002
Lithium	0.0002	0.0051	0.1294	0.0003	0.0055	0.5420		0.0001	0.0001	0.0001	0.0001
*Mg	0.0426	0.9329		0.0602	1.2232			0.0580	0.0481	0.0610	0.0624
Mn	0.0007	0.0147	0.3733	0.0007	0.0144	1.4140		0.0003	0.0002	0.0002	0.0003
Mo	0.0001	0.0027	0.0683	0.0001	0.0015	0.1480		0.0000	0.0000	0.0000	0.0000
Nd	0.0002	0.0037	0.0950	0.0001	0.0029	0.2860		0.0004	0.0002	0.0002	0.0006
Nickel	0.0001	0.0025	0.0639	0.0001	0.0027	0.2680		0.0007	0.0004	0.0001	0.0003
Pr	0.0000	0.0003	0.0083	0.0000	0.0004	0.0380		0.0000	0.0000	0.0000	0.0000
Ruthenium	0.0005	0.0115	0.2917	0.0003	0.0053	0.5240		0.0001	0.0000	0.0000	0.0001
Samarium	0.0005	0.0108	0.2739	0.0005	0.0108	1.0660		0.0001	0.0001	0.0001	0.0001
*Strontium	0.0070	0.1537		0.0075	0.1516			0.0025	0.0025	0.0024	0.0024
Terbium	0.0000	0.0002	0.0056	0.0000	0.0002	0.0200		0.0000	0.0000	0.0000	0.0000
Titanium	0.0007	0.0147	0.3717	0.0008	0.0155	1.5260		0.0004	0.0004	0.0005	0.0005
*Zirconium	0.0083	0.1820		0.0065	0.1315			0.0019	0.0016	0.0016	0.0020
*Others	0.0693	1.5171		0.0859	1.7451			0.0780	0.0636	0.0726	0.0813
mg, Metals Found	4.5663	100.0000	49.1128	4.9217	100.0000	115.1220		1.4900	1.4464	1.4943	1.4708
mg, Filter Loading	0.1800			0.0500							

*High Al, Ba, B, Mg, Europium (?), Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

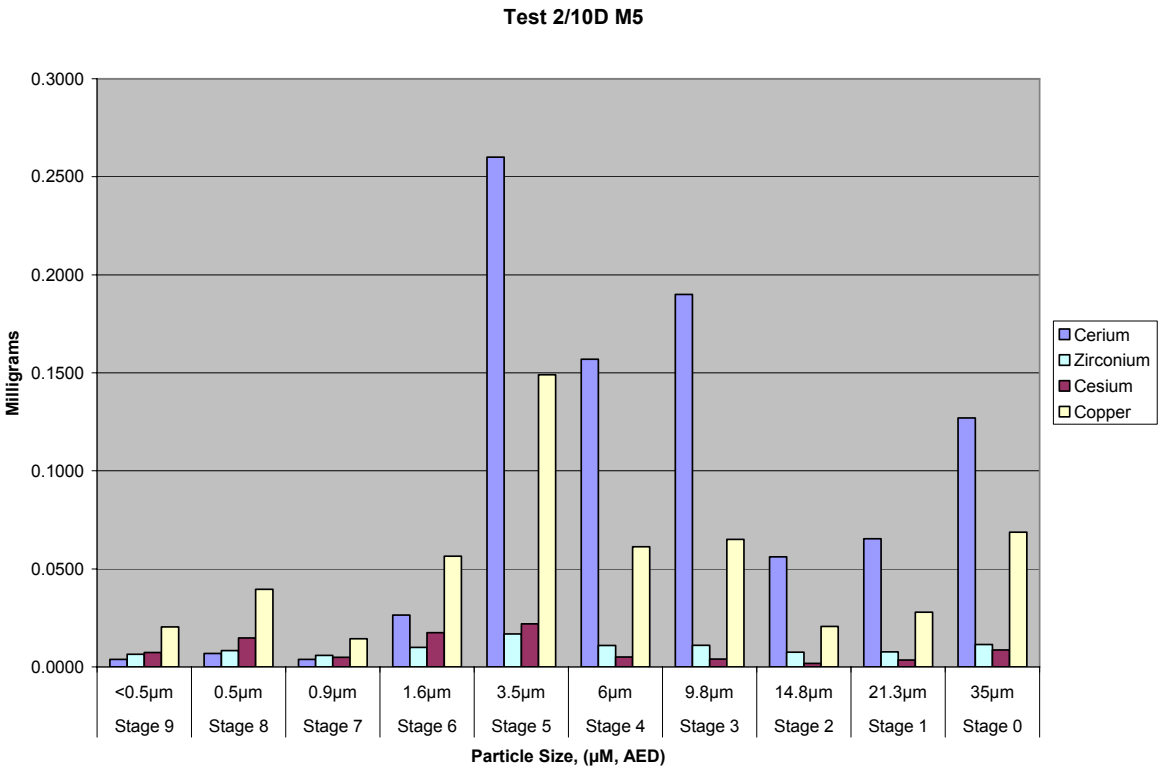


Figure A2.10D.69 Test 2/10D Marple M5 Metals Analysis Distribution, mg

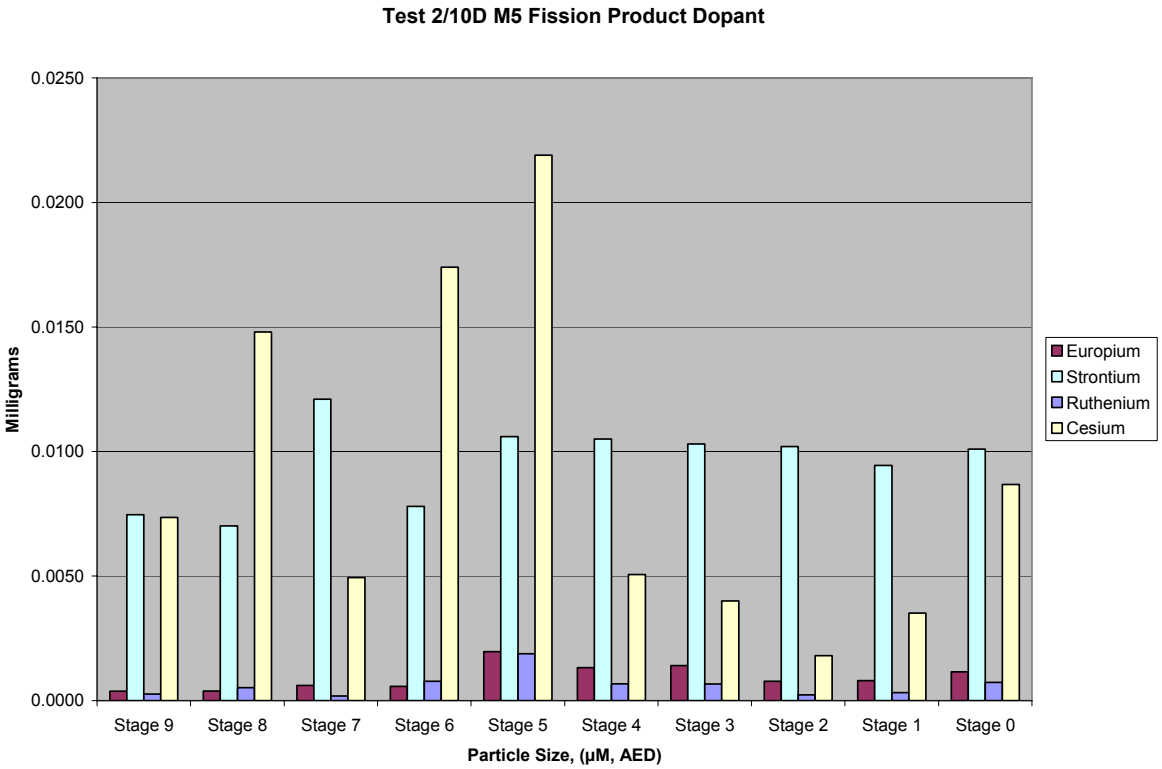


Figure A2.10D.70 Test 2/10D Marple M5 Fission Product Dopant Distribution, mg

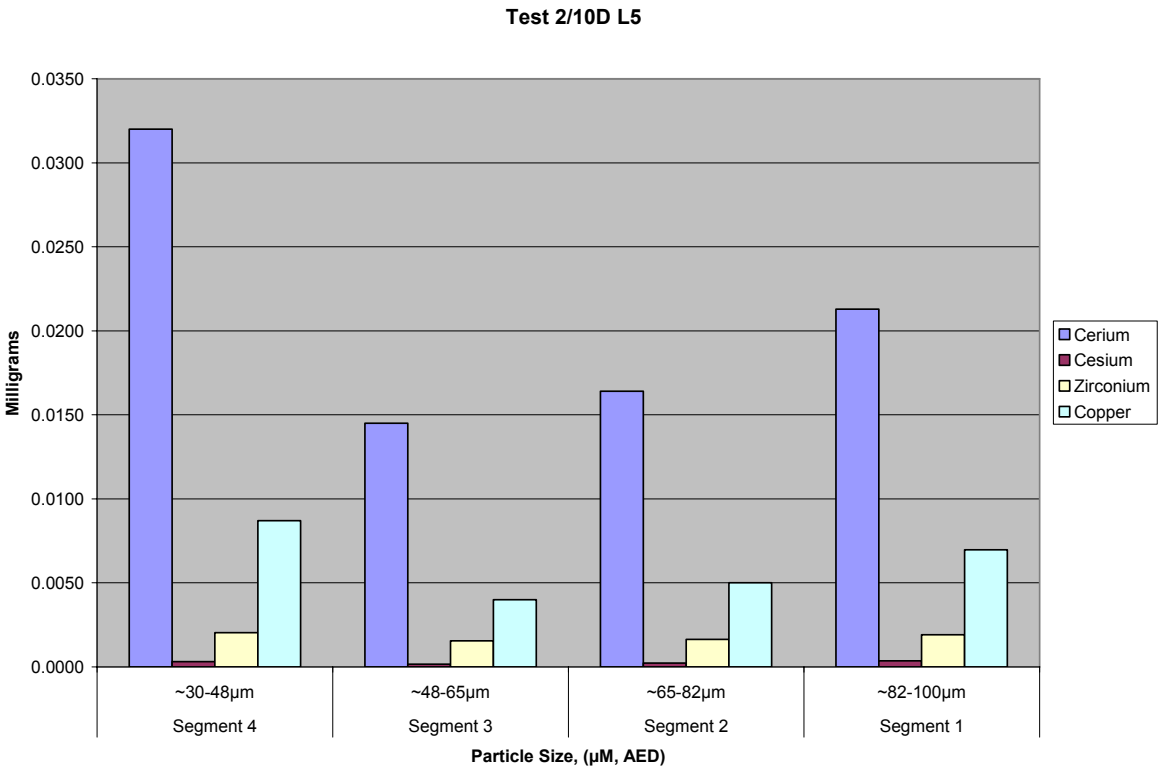


Figure A2.10D.71 Test 2/10D LPS L5 Metals Analysis Distribution, mg

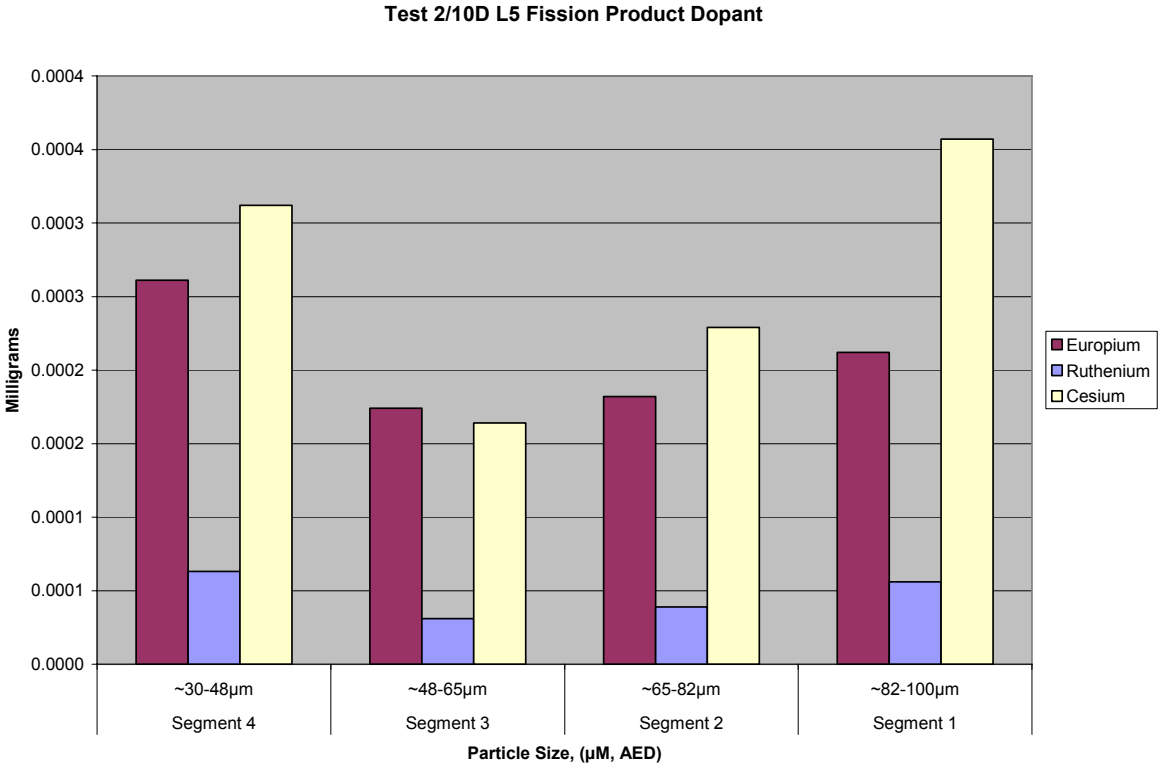


Figure A2.10D.72 Test 2/10D LPS L5 Fission Product Dopant Distribution, mg

Table A2.10D.57 Test 2/10D Marple M6 Elemental Analyses, Stages 0-3

2/10D	STAGE 0			STAGE 1			STAGE 2			STAGE 3		
M6	Particle size 35 µm			Particle size 21.3 µm			Particle size 14.8 µm			Particle size 9.8 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	1.0900	22.8488		0.9510	23.0332		1.1600	23.2371		0.9920	21.9922	
Antimony	0.0000	0.0005	0.0016	0.0000	0.0006	0.0125	0.0000	0.0005	0.0139	0.0000	0.0006	0.0056
*Barium	1.7600	36.8935		1.7300	41.9006		2.0700	41.4662		1.8400	40.7920	
*Boron	1.4500	30.3952		1.3000	31.4860		1.6100	32.2515		1.4300	31.7025	
Cerium	0.1550	3.2491	9.8726	0.0424	1.0269	21.2000	0.0454	0.9095	25.2222	0.0921	2.0418	20.4667
Cesium	0.0118	0.2474	0.7516	0.0035	0.0848	1.7500	0.0016	0.0310	0.8611	0.0032	0.0716	0.7178
Chromium	0.0009	0.0183	0.0557	0.0005	0.0122	0.2510	0.0005	0.0102	0.2828	0.0005	0.0111	0.1116
Copper	0.0962	2.0166	6.1274	0.0215	0.5207	10.7500	0.0149	0.2985	8.2778	0.0412	0.9134	9.1556
Europium	0.0018	0.0382	0.1159	0.0005	0.0124	0.2570	0.0006	0.0118	0.3261	0.0009	0.0204	0.2047
Iron	0.1010	2.1172	6.4331	0.0283	0.6854	14.1500	0.0277	0.5549	15.3889	0.0522	1.1573	11.6000
La	0.0001	0.0018	0.0056	0.0001	0.0017	0.0360	0.0001	0.0017	0.0478	0.0001	0.0016	0.0164
Lead	0.0005	0.0096	0.0290	0.0004	0.0091	0.1880	0.0004	0.0089	0.2467	0.0004	0.0086	0.0864
Lithium	0.0002	0.0051	0.0154	0.0002	0.0051	0.1045	0.0003	0.0051	0.1428	0.0002	0.0050	0.0500
*Mg	0.0782	1.6392		0.0372	0.9010		0.0448	0.8974		0.0408	0.9045	
Mn	0.0015	0.0312	0.0949	0.0006	0.0154	0.3180	0.0007	0.0140	0.3889	0.0009	0.0192	0.1927
Mo	0.0002	0.0035	0.0107	0.0000	0.0008	0.0165	0.0000	0.0004	0.0106	0.0000	0.0008	0.0076
Nd	0.0024	0.0495	0.1503	0.0005	0.0117	0.2420	0.0001	0.0027	0.0750	0.0015	0.0326	0.3267
Nickel	0.0002	0.0047	0.0141	0.0001	0.0032	0.0665	0.0001	0.0025	0.0689	0.0002	0.0034	0.0340
Pr	0.0000	0.0005	0.0014	0.0000	0.0004	0.0080	0.0000	0.0004	0.0100	0.0000	0.0004	0.0038
Ruthenium	0.0011	0.0231	0.0701	0.0003	0.0062	0.1275	0.0002	0.0032	0.0889	0.0005	0.0100	0.1004
Samarium	0.0005	0.0103	0.0311	0.0004	0.0102	0.2115	0.0005	0.0106	0.2939	0.0005	0.0105	0.1049
*Strontium	0.0077	0.1622		0.0062	0.1497		0.0077	0.1534		0.0070	0.1550	
Terbium	0.0000	0.0005	0.0017	0.0000	0.0002	0.0050	0.0000	0.0002	0.0056	0.0000	0.0004	0.0036
Titanium	0.0009	0.0181	0.0550	0.0006	0.0142	0.2925	0.0010	0.0208	0.5778	0.0006	0.0137	0.1373
*Zirconium	0.0103	0.2159		0.0045	0.1083		0.0054	0.1076		0.0059	0.1315	
*Others	0.1883	3.9481		0.0695	1.6837		0.0770	1.5421		0.0988	2.1900	
mg, Metals Found	4.7705	100.0000	23.8373	4.1288	100.0000	49.9865	4.9920	100.0000	52.3294	4.5107	100.0000	43.3256
mg, Filter Loading	1.5700			0.2000			0.1800			0.4500		

*High Al, Ba, B, Mg, Europium (?), Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A2.10D.58 Test 2/10D Marple M6 Elemental Analyses, Stages 4-7

2/10D	STAGE 4			STAGE 5			STAGE 6			STAGE 7		
M6	Particle size 6.0 µm			Particle size 3.5 µm			Particle size 1.55 µm			Particle size 0.93 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	1.2000	22.7954		1.1900	21.2444		1.2000	22.5769		1.2400	22.7169	
Antimony	0.0000	0.0005	0.0066	0.0000	0.0004	0.0037	0.0000	0.0005	0.0132	0.0000	0.0005	0.0147
*Barium	2.0900	39.7021		2.2200	39.6324		2.2000	41.3910		2.2600	41.4033	
*Boron	1.6900	32.1036		1.7600	31.4203		1.7200	32.3602		1.8000	32.9761	
Cerium	0.1130	2.1466	29.7368	0.1950	3.4812	28.6765	0.0464	0.8730	24.4211	0.0140	0.2565	8.2353
Cesium	0.0037	0.0709	0.9816	0.0109	0.1946	1.6029	0.0067	0.1253	3.5053	0.0102	0.1869	6.0000
Chromium	0.0006	0.0106	0.1463	0.0007	0.0122	0.1004	0.0006	0.0107	0.2984	0.0006	0.0114	0.3647
Copper	0.0376	0.7143	9.8947	0.0726	1.2961	10.6765	0.0328	0.6171	17.2632	0.0347	0.6357	20.4118
Europium	0.0010	0.0181	0.2505	0.0014	0.0248	0.2044	0.0006	0.0120	0.3368	0.0005	0.0085	0.2735
Iron	0.0501	0.9517	13.1842	0.0704	1.2568	10.3529	0.0345	0.6491	18.1579	0.0271	0.4965	15.9412
La	0.0001	0.0017	0.0232	0.0001	0.0017	0.0143	0.0001	0.0017	0.0484	0.0001	0.0016	0.0529
Lead	0.0005	0.0088	0.1216	0.0005	0.0090	0.0738	0.0005	0.0092	0.2584	0.0005	0.0089	0.2865
Lithium	0.0003	0.0050	0.0687	0.0003	0.0048	0.0396	0.0003	0.0051	0.1432	0.0003	0.0051	0.1635
*Mg	0.0575	1.0923		0.0546	0.9747		0.0543	1.0216		0.0516	0.9453	
Mn	0.0009	0.0173	0.2397	0.0012	0.0207	0.1706	0.0008	0.0156	0.4368	0.0008	0.0145	0.4647
Mo	0.0000	0.0007	0.0095	0.0001	0.0017	0.0144	0.0001	0.0010	0.0289	0.0001	0.0016	0.0500
Nd	0.0011	0.0201	0.2789	0.0007	0.0122	0.1004	0.0004	0.0068	0.1900	0.0002	0.0036	0.1147
Nickel	0.0001	0.0028	0.0387	0.0002	0.0033	0.0269	0.0001	0.0023	0.0653	0.0001	0.0022	0.0694
Pr	0.0000	0.0004	0.0053	0.0000	0.0004	0.0035	0.0000	0.0004	0.0100	0.0000	0.0003	0.0100
Ruthenium	0.0004	0.0085	0.1179	0.0010	0.0177	0.1459	0.0005	0.0089	0.2495	0.0005	0.0083	0.2659
Samarium	0.0005	0.0102	0.1413	0.0006	0.0103	0.0847	0.0005	0.0103	0.2874	0.0005	0.0100	0.3212
*Strontium	0.0082	0.1550		0.0089	0.1585		0.0080	0.1503		0.0081	0.1488	
Terbium	0.0000	0.0004	0.0050	0.0000	0.0005	0.0043	0.0000	0.0002	0.0053	0.0000	0.0002	0.0059
Titanium	0.0009	0.0178	0.2471	0.0012	0.0212	0.1750	0.0011	0.0205	0.5737	0.0009	0.0171	0.5500
*Zirconium	0.0077	0.1455		0.0112	0.1999		0.0069	0.1302		0.0077	0.1405	
*Others	0.1136	2.1582		0.1319	2.3549		0.0939	1.7671		0.0834	1.5272	
mg, Metals Found	5.2642	100.0000	55.4976	5.6015	100.0000	52.4707	5.3152	100.0000	66.2926	5.4585	100.0000	53.5959
mg, Filter Loading	0.3800			0.6800			0.1900			0.1700		

*High Al, Ba, B, Mg, Europium (?), Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A2.10D.59 Test 2/10D Marple M6 Elemental Analyses, Stages 8-9 & LPS L6

2/10D	STAGE 8			STAGE 9				LPS L6			
M6	Particle size 0.52 µm			Particle size final, <0.5 µm				S1: ~82-100 µm	S2: ~65-82 µm	S3: ~48-65 µm	S4: ~30-48 µm
	mg	% detect	% loading	mg	% detect	% loading		mg	mg	mg	mg
*Aluminum	1.2400	23.1902		1.3000	22.8732			0.4000	0.3870	0.3790	0.3590
Antimony	0.0000	0.0005	0.0132	0.0000	0.0004	0.0167		0.0000	0.0000	0.0000	0.0000
*Barium	2.2200	41.5180		2.3500	41.3477			0.5410	0.5450	0.5600	0.5540
*Boron	1.7300	32.3541		1.8700	32.9022			0.4470	0.4720	0.3900	0.4100
Cerium	0.0083	0.1549	4.3579	0.0062	0.1086	4.1133		0.0099	0.0103	0.0128	0.0507
Cesium	0.0140	0.2618	7.3684	0.0106	0.1865	7.0667		0.0003	0.0002	0.0002	0.0008
Chromium	0.0007	0.0126	0.3537	0.0006	0.0114	0.4307		0.0003	0.0003	0.0002	0.0003
Copper	0.0390	0.7294	20.5263	0.0307	0.5402	20.4667		0.0032	0.0031	0.0039	0.0167
Europium	0.0004	0.0078	0.2205	0.0004	0.0076	0.2893		0.0001	0.0001	0.0002	0.0004
Iron	0.0241	0.4507	12.6842	0.0246	0.4328	16.4000		0.0091	0.0081	0.0094	0.0227
La	0.0001	0.0017	0.0479	0.0001	0.0019	0.0707		0.0000	0.0000	0.0000	0.0000
Lead	0.0005	0.0092	0.2584	0.0006	0.0113	0.4293		0.0002	0.0002	0.0002	0.0002
Lithium	0.0003	0.0050	0.1416	0.0003	0.0054	0.2053		0.0001	0.0001	0.0001	0.0001
*Mg	0.0496	0.9276		0.0681	1.1982			0.0589	0.0648	0.0646	0.0614
Mn	0.0008	0.0142	0.3989	0.0008	0.0145	0.5493		0.0002	0.0002	0.0002	0.0003
Mo	0.0001	0.0022	0.0621	0.0001	0.0017	0.0660		0.0000	0.0000	0.0000	0.0000
Nd	0.0001	0.0017	0.0484	0.0002	0.0031	0.1193		0.0001	0.0002	0.0003	0.0012
Nickel	0.0001	0.0023	0.0653	0.0001	0.0018	0.0667		0.0001	0.0000	0.0000	0.0001
Pr	0.0000	0.0003	0.0095	0.0000	0.0004	0.0140		0.0000	0.0000	0.0000	0.0000
Ruthenium	0.0005	0.0097	0.2721	0.0004	0.0070	0.2640		0.0000	0.0000	0.0000	0.0001
Samarium	0.0005	0.0100	0.2821	0.0006	0.0102	0.3847		0.0001	0.0001	0.0001	0.0001
*Strontium	0.0079	0.1472		0.0088	0.1555			0.0024	0.0025	0.0024	0.0024
Terbium	0.0000	0.0002	0.0053	0.0000	0.0002	0.0067		0.0000	0.0000	0.0000	0.0000
Titanium	0.0010	0.0180	0.5058	0.0010	0.0175	0.6627		0.0004	0.0005	0.0004	0.0004
*Zirconium	0.0091	0.1707		0.0091	0.1608			0.0014	0.0016	0.0015	0.0028
*Others	0.0783	1.4641		0.0977	1.7184			0.0697	0.0747	0.0759	0.0872
mg, Metals Found	5.3471	100.0000	47.6216	5.6835	100.0000	51.6220		1.4750	1.4964	1.4257	1.4838
mg, Filter Loading	0.1900			0.1500							

*High Al, Ba, B, Mg, Europium (?), Strontium, Zirconium content due to filter blank content (not included in loading)
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

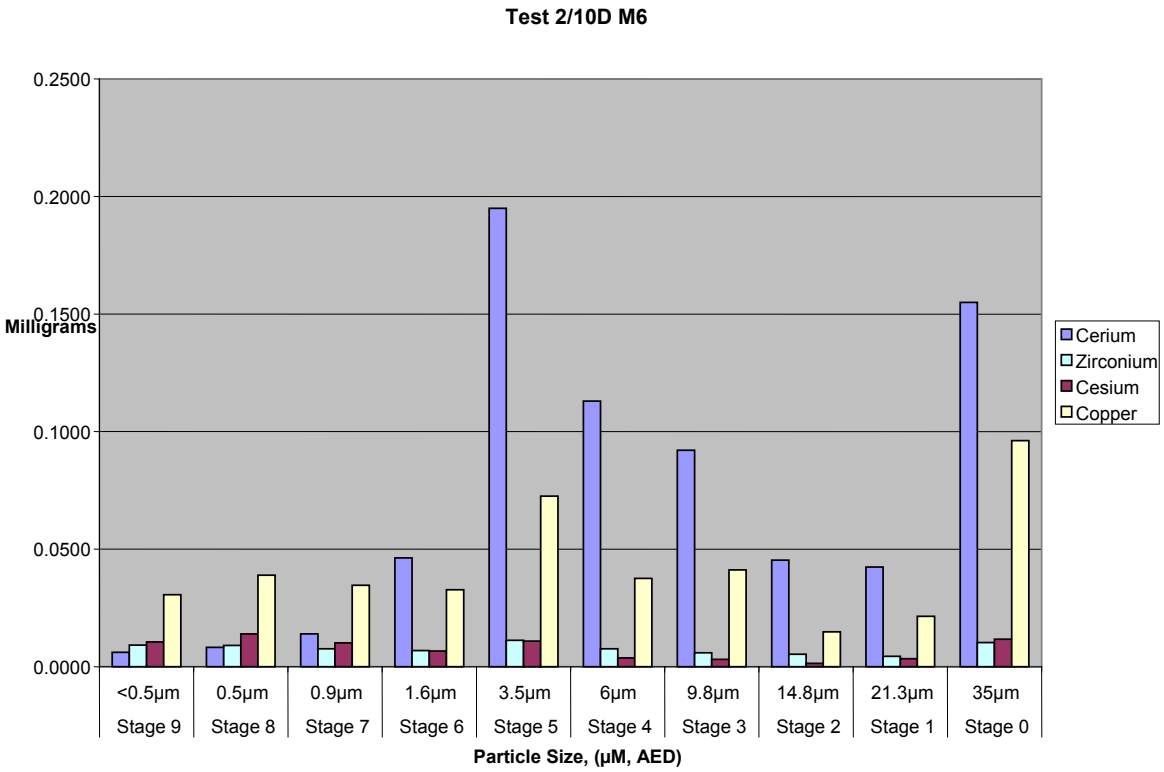


Figure A2.10D.73 Test 2/10D Marple M6 Metals Analysis Distribution, mg

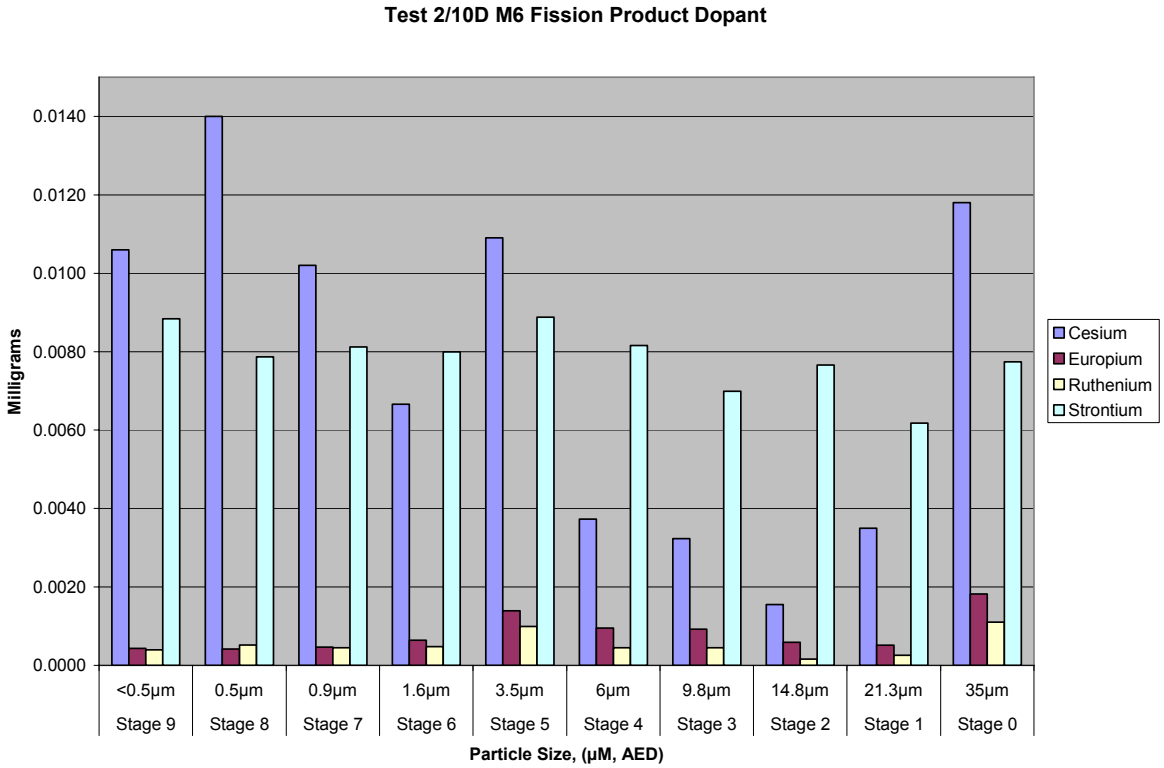


Figure A2.10D.74 Test 2/10D Marple M6 Fission Product Dopant Distribution, mg

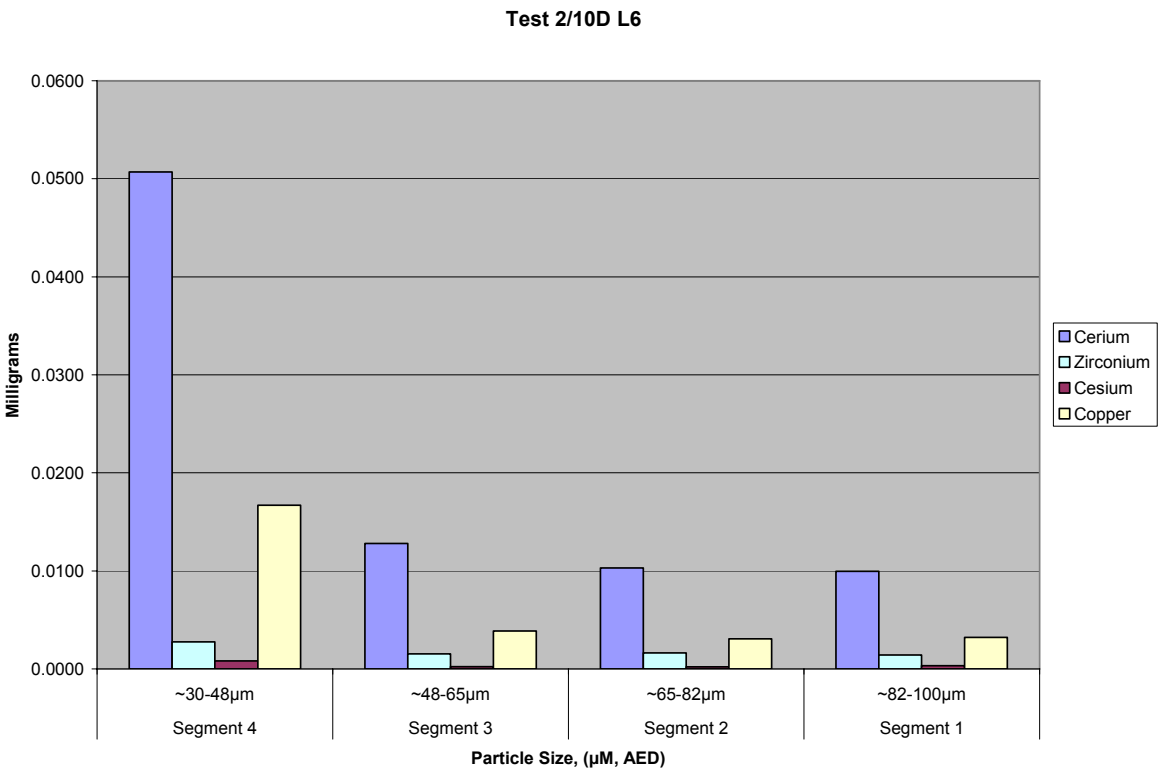


Figure A2.10D.75 Test 2/10D LPS L6 Metals Analysis Distribution, mg

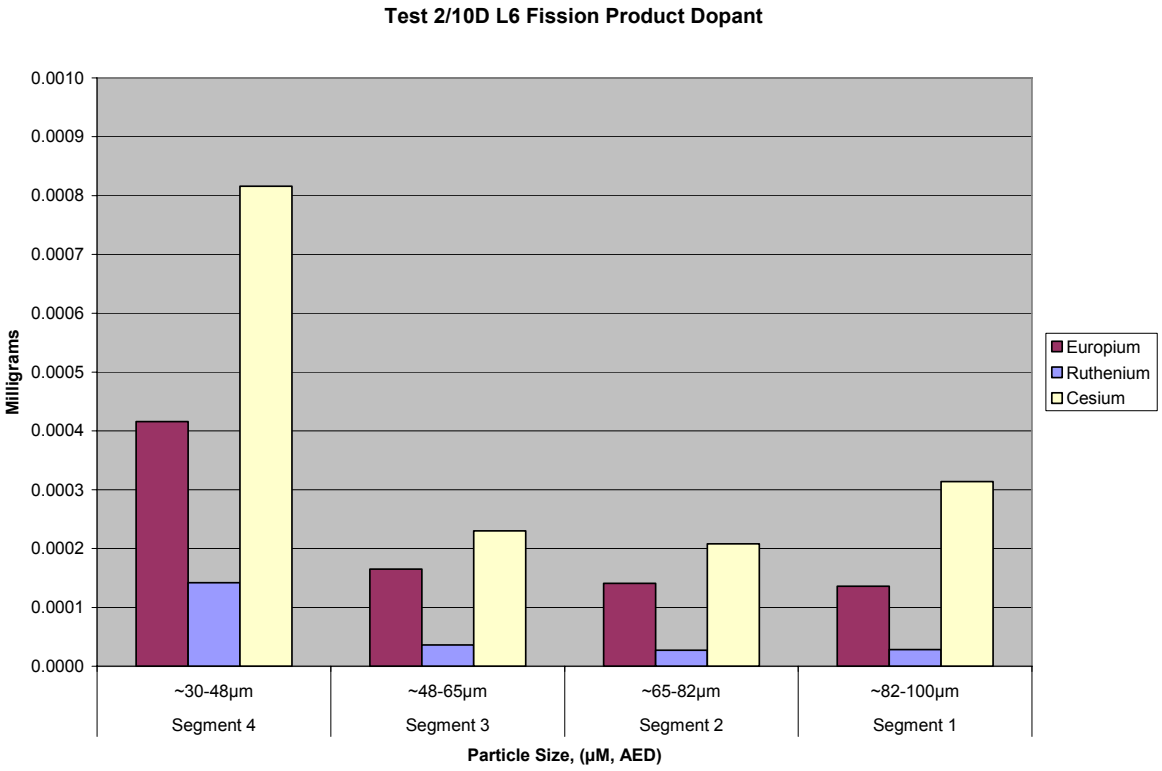


Figure A2.10D.76 Test 2/10D LPS L6 Fission Product Dopant Distribution, mg

A.2.10E Test 2/10E Analyses and Results

Particulates from test 2/10E were sampled using four independent Large Particle Separator and Marple impactor systems, both with fiberglass substrates. In addition, multiple separate impact particle debris samples were collected by a HEPA vacuum system and a pre-separator paper liner (collection bag). The total measured (net) weight of this impact debris was 19.719 g. Surface deposited particle samples were also obtained from the exterior and interior of each of the four internal chamber sampling tubes. All samples collected were weighed, then packaged and shipped to the Fraunhofer Institute in Germany for subsequent post-test chemical analyses. Graphs of gravimetric particle size distributions from the four 2/10E Marple impactors, plus the mass concentrations, are presented in Figures A2.10E.77 to Figure A2.10E.81.

[Particle chemical analyses are not available. TBD.]

A.2.10F Test 2/10F Analyses and Results

Particulates from test 2/10F, the replicate for test 2/10E, were sampled using four independent Large Particle Separator and Marple impactor systems, both with fiberglass substrates. In addition, multiple separate impact particle debris samples were collected by a HEPA vacuum system and a pre-separator paper liner (collection bag). The total measured (net) weight of this impact debris was 23.706 g. Surface deposited particle samples were also obtained from the exterior and interior of each of the four internal chamber sampling tubes. All samples collected were weighed, then packaged and shipped to the Fraunhofer Institute in Germany for subsequent post-test chemical analyses. Graphs of gravimetric particle size distributions from the four 2/10F Marple impactors, plus the mass concentrations, are presented in Figures A2.10F.82 to Figure A2.10F.86.

[Particle chemical analyses are not available. TBD.]

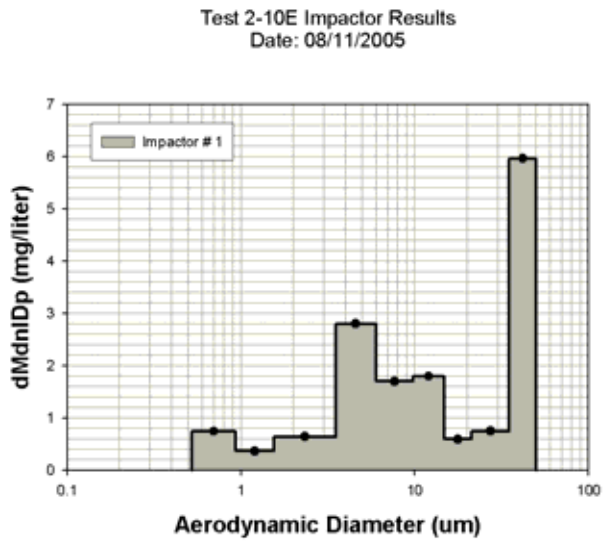


Figure A2.10E.77 Test 2/10E Marple #1 Size Distribution

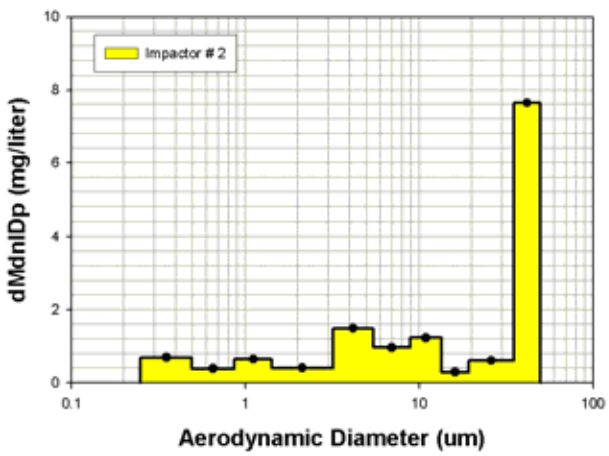


Figure A2.10E.78 Test 2/10E Marple #2 Size Distribution

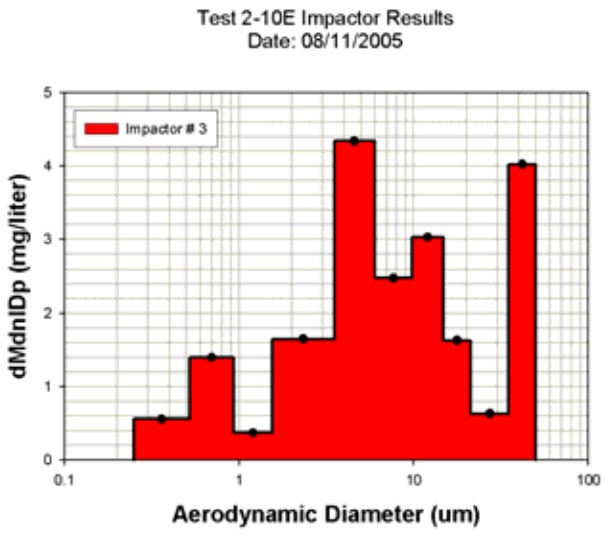


Figure A2.10E.79 Test 2/10E Marple #3 Size Distribution

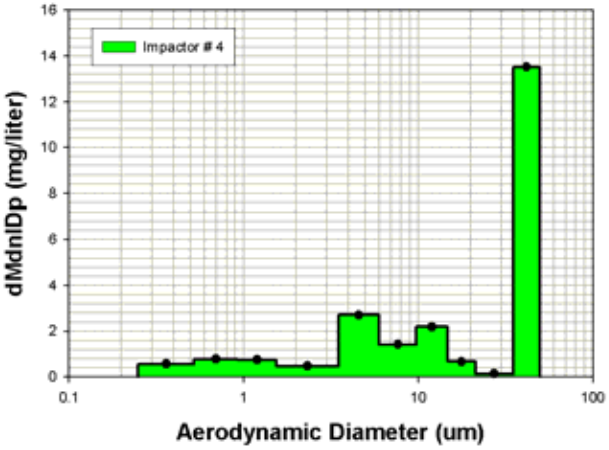


Figure A2.10E.80 Test 2/10E Marple #4 Size Distribution

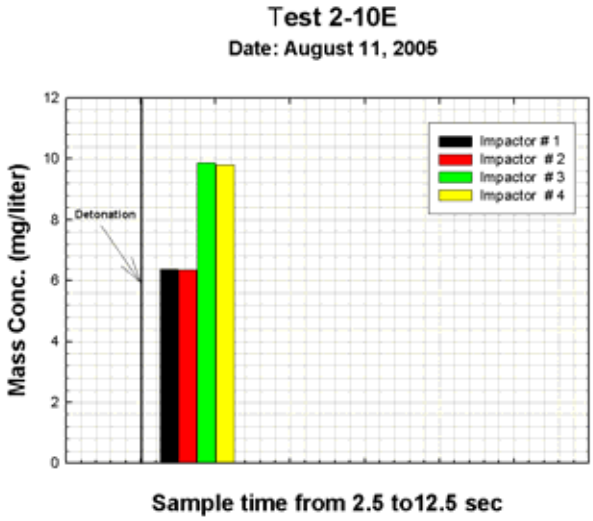


Figure A2.10E.81 Test 2/10E Marple Impactor Mass Concentration Data

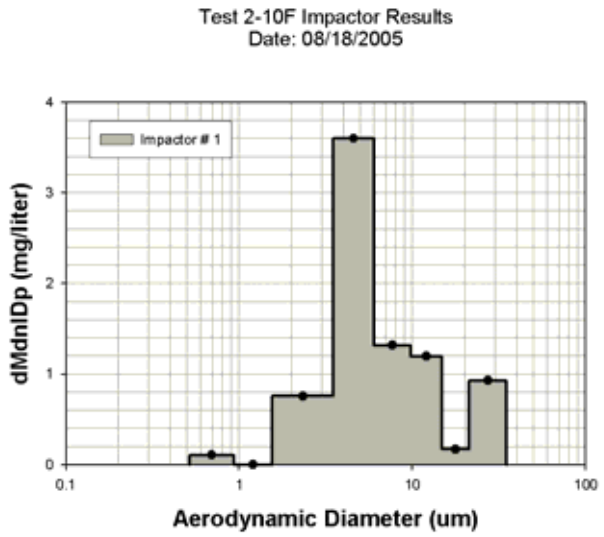


Figure A2.10F.82 Test 2/10F Marple #1 Size Distribution

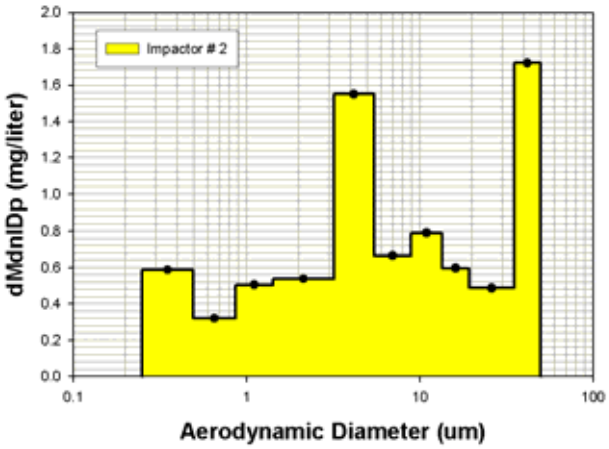


Figure A2.10F.83 Test 2/10F Marple #2 Size Distribution

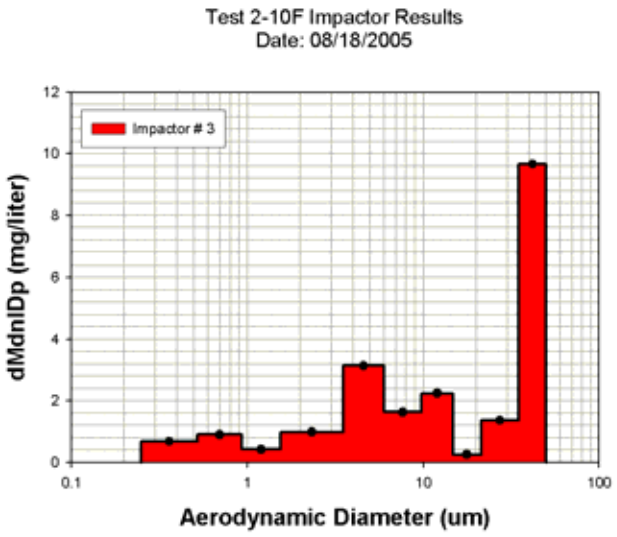


Figure A2.10F.84 Test 2/10F Marple #3 Size Distribution

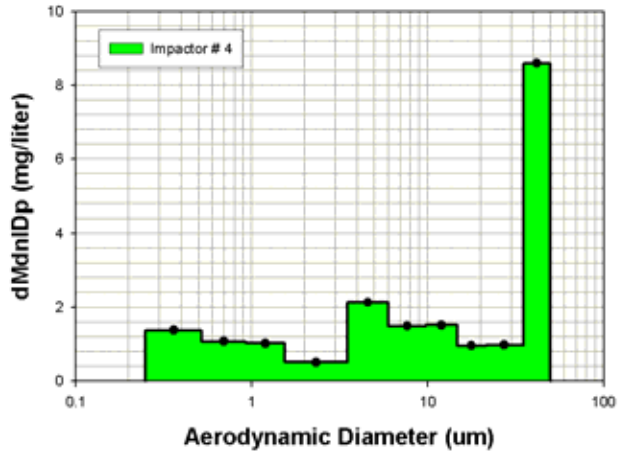


Figure A2.10F.85 Test 2/10F Marple #4 Size Distribution

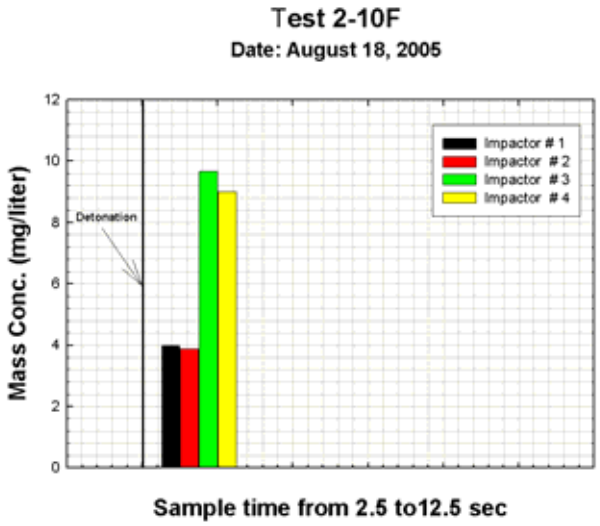


Figure A2.10F.86 Test 2/10F Marple Impactor Mass Concentration Data

A.3 Aerosol Particle Measurements, Phase 3 Tests

A.3.2A Test 3/2 (A) Analyses and Results

Particulates from the Phase 3 DUO_2 test 3/2 (A) were sampled using four independent Marple impactor and Large Particle Separator systems. In addition, multiple separate impact particle debris samples were collected by a HEPA vacuum system and a pre-separator paper liner (collection bag). The impact particle debris was subsequently mechanically sieved and chemically analyzed by ICP-MS. Surface deposited particle samples were also obtained from the exterior and interior of each of the four internal chamber sampling tubes. All sample materials collected contain depleted uranium and were, therefore, slightly radioactive. These samples required special, appropriate handling.

Gravimetric and Debris Analyses: Graphs of gravimetric particle size distributions from the four 3/2 (A) Marple impactors, plus the mass concentrations, are presented in Figures A3.2A.1 to Figure A3.2A.5. The weight distribution of the sieved particle impact debris is presented in Table A3.2A.1. Table A3.2A.2 contains the measured impact debris elemental analysis, in mg/kg, for the particles from 90 to 38 µm (geometric) size, or 290 to 123 µm AED for DUO_2 particles. The weight percent distribution of metals on the impact debris sieved fractions is plotted in Figure A3.2A.6. The fission product species Cs, Ru, Sr, and Eu are not plotted; they are present only as minimal impurities.

NOTE: During chemical dissolution of the debris samples (in D10, debris in the pre-separator liner collection bag), aluminum foil covering the sample beakers partially fell into the solution as a contaminant. The aluminum foil was also analyzed to determine its content, and is included in Table A3.2A.2.

Table A3.2A.1 Test 3/2 (A), Weight Distribution of Impact Debris

Particle Density		Particle Density 95%				
1.00 g/cc		10.41 g/cc				
Sieve #	Opening Size (geom.)	AED Size for DUO_2	Weight, g Retained	Weight, g Passed	Percent Passed	Percent Retained
25	710 µm	2290 µm	15.14	6.75	30.8%	69.2%
35	500 µm	1610 µm	0.84	5.90	27.0%	3.9%
60	250 µm	807 µm	2.28	3.62	16.5%	10.4%
120	125 µm	403 µm	1.78	1.84	8.4%	8.2%
170	90 µm	290 µm	1.36	0.48	2.2%	6.2%
200	75 µm	242 µm	0.09	0.39	1.8%	0.4%
400	38 µm	123 µm	0.39	0.00	0.0%	1.8%
600	25 µm	81 µm	**0.00**	**0.00**	**0.0%**	**0.0%**
pan	< 25 µm	< 81 µm	**0.00**	**0.00**	**0.0%**	**0.0%**
totals			21.89			100.0%

Marple and LPS Particle Element Analyses: Chemical analyses were performed on all four of the Marple and LPS particle collection systems. Each Large Particle Sampler fiberglass substrate was cut into four separate pieces prior to chemical dissolution and elemental analysis by ICP-MS. These LPS segments cover the nominal particle size range of: Segment #1 is ~82-100 µm AED, Segment #2 is ~65-82 µm AED, Segment #3 is ~48-65 µm AED, and Segment #4 is ~30-48 µm AED.

All Marple M1 elemental analyses are listed in Tables A3.2A.3 to A3.2A.5 and are plotted in Figure A3.2A.7 for metals. All LPS L1 elemental analyses are listed in Table A3.2A.6 and are plotted in Figure A3.2A.8 for metals. Again, the fission product species Cs, Ru, Sr, and Eu are not plotted; they are present only as minimal impurities.

All Marple M2 elemental analyses are listed in Tables A3.2A.7 to A3.2A.9 and are plotted in Figure A3.2A.9. All LPS L2 elemental analyses are listed in Table A3.2A.10 and are plotted in Figure A3.2A.10.

All Marple M3 elemental analyses are listed in Tables A3.2A.11 to A3.2A.13 and are plotted in Figure A3.2A.11. All LPS L3 elemental analyses are listed in Table A3.2A.14 and are plotted in Figure A3.2A.12.

All Marple M4 elemental analyses are listed in Tables A3.2A.15 to A3.2A.17 and are plotted in Figure A3.2A.13. All LPS L4 elemental analyses are listed in Table A3.2A.18 and are plotted in Figure A3.2A.14.

Table A3.2A.2 Test 3/2 (A) Impact Debris Metals Distribution, mg/kg

3/2 D10 mg/kg	D10-38	D10-75	D10-90			Aluminum Foil	
Sieve Opening	38 µm	75 µm	90 µm			(dissolution contaminant)	
*Aluminum	6550.00	8640.00	4800.00			*Aluminum	60800.00
*Barium	2.78	3.25	2.39			*Barium	0.03
*Boron	5.86	23.50	5.05			*Boron	0.51
Cerium	9300.00	10300.00	7140.00			Cerium	0.04
Cesium	9.92	10.90	5.16			Cesium	0.01
Chromium	271.00	345.00	217.00			Chromium	1.87
Copper	12600.00	15500.00	11700.00			Copper	0.90
Europium	0.21	0.55	0.14			Europium	0.01
Iron	41200.00	61500.00	38600.00			Iron	422.00
Lanthanum	2.02	3.29	2.41			Lanthanum	0.03
Lead	40.60	62.60	29.90			Lead	0.53
Lithium	2.51	4.77	2.49			Lithium	0.63
*Magnesium	207.00	305.00	165.00			*Magnesium	3.19
Manganese	562.00	793.00	511.00			Manganese	2.84
Molybdenum	23.10	36.90	21.70			Molybdenum	0.07
Neodymium	100.00	111.00	82.50			Neodymium	0.02
Nickel	168.00	232.00	138.00			Nickel	1.60
Praseodymium	0.54	0.77	0.55			Praseodymium	0.01
Ruthenium	0.66	0.87	0.37			Ruthenium	0.01
Samarium	0.61	0.77	0.59			Samarium	0.01
*Strontium	1.77	3.16	1.39			*Strontium	0.13
Terbium	0.93	1.05	0.76			Terbium	0.01
Titanium	182.00	236.00	147.00			Titanium	3.05
*Zirconium	6710.00	6970.00	4720.00			*Zirconium	0.30
Antimony	171.00	205.00	96.70			Antimony	13.90
Tin	51.20	235.00	78.90			Tin	5.00
Uranium	655000.00	758000.00	601000.00			Uranium	0.23
Others	42929.0110	63832.9270	40013.2450			Others	449.1436
mg, Metals Found	733163.71	863524.37	669468.99			mg, Metals Found	61256.93

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)
NOTE: Species in grey cells are minor impurity contents
Others: Sb, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Sm, Tb, Ti

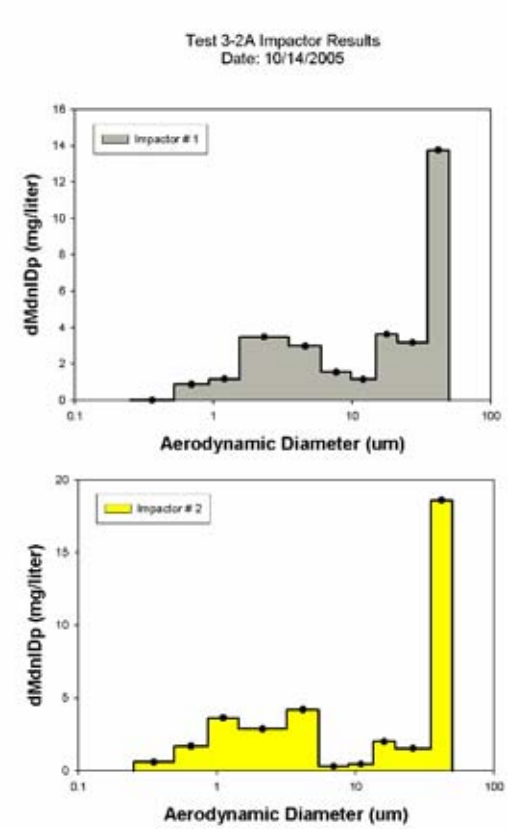


Figure A3.2A.1 Test 3/2 (A) Marple #1 Size Distribution

Figure A3.2A.2 Test 3/2 (A) Marple #2 Size Distribution

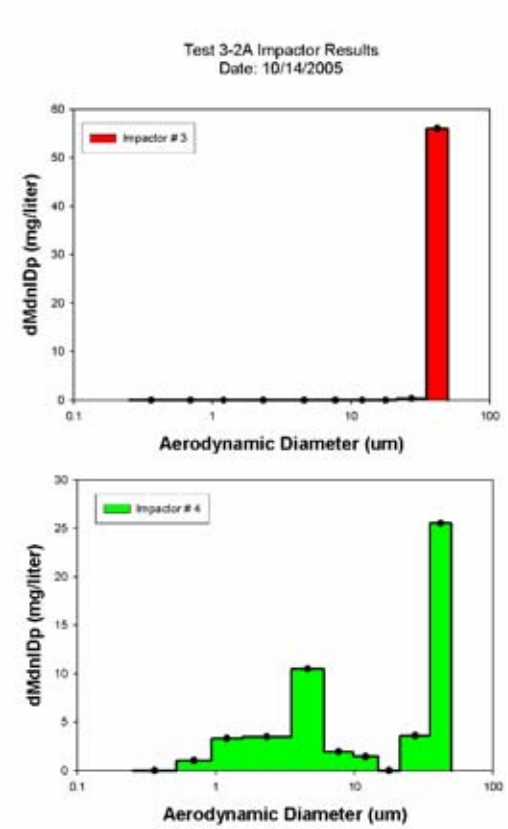


Figure A3.2A.3 Test 3/2 (A) Marple #3 Size Distribution

Figure A3.2A.4 Test 3/2 (A) Marple #4 Size Distribution

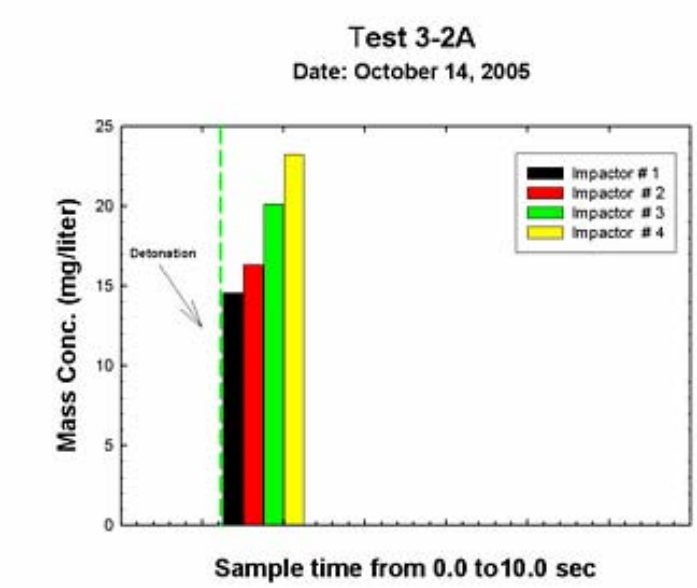


Figure A3.2A.5 Test 3/2 (A) Marple Impactor Mass Concentration Data

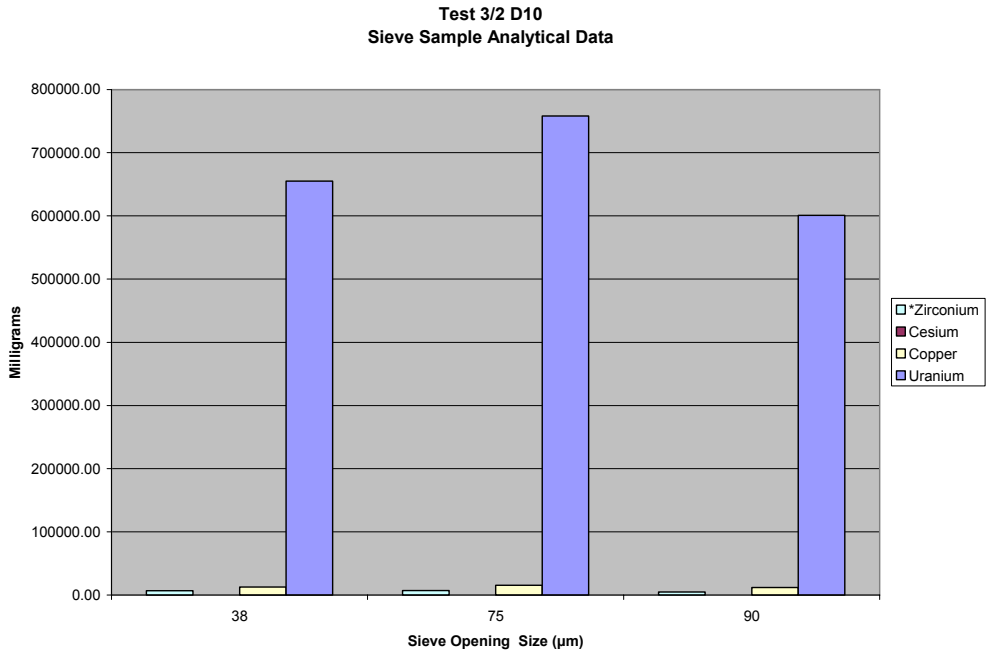


Figure A3.2A.6 Test 3/2 (A) Metals Weight Percent Distribution, Impact Debris Fractions

Table A3.2A.3 Test 3/2 (A) Marple M1 Elemental Analyses, Stages 0-3

3/2 (A)	STAGE 0			STAGE 1			STAGE 2			STAGE 3		
M1	Particle size 35 μm			Particle size 21.3 μm			Particle size 14.8 μm			Particle size 9.8 μm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	1.56	22.2102		1.46	22.3375		1.51	21.4467		1.6	22.6572	
*Barium	2.68	38.1559		2.61	39.9320		2.86	40.6208		2.79	39.5085	
*Boron	2.29	32.6034		2.17	33.2002		2.44	34.6555		2.46	34.8354	
Cerium	0.00494	0.0703	0.3167	0.00194	0.0297	0.3880	0.00103	0.0146	0.2452	0.00134	0.0190	0.8933
Cesium	0.000092	0.0013	0.0059	0.000035	0.0005	0.0070	0.00002	0.0003	0.0048	0.000018	0.0003	0.0120
Chromium	0.0067	0.0954	0.4295	0.00266	0.0407	0.5320	0.00131	0.0186	0.3119	0.000992	0.0140	0.6613
Copper	0.0663	0.9439	4.2500	0.035	0.5355	7.0000	0.0205	0.2912	4.8810	0.0104	0.1473	6.9333
Europium	0.000528	0.0075	0.0338	0.000487	0.0075	0.0974	0.000468	0.0066	0.1114	0.000491	0.0070	0.3273
Iron	0.119	1.6942	7.6282	0.0647	0.9899	12.9400	0.0453	0.6434	10.7857	0.0376	0.5324	25.0667
La	0.00012	0.0017	0.0077	0.000108	0.0017	0.0216	0.000109	0.0015	0.0260	0.000106	0.0015	0.0707
Lead	0.00127	0.0181	0.0814	0.000918	0.0140	0.1836	0.000836	0.0119	0.1990	0.000742	0.0105	0.4947
Lithium	0.000411	0.0059	0.0263	0.000408	0.0062	0.0816	0.000427	0.0061	0.1017	0.00041	0.0058	0.2733
*Mg	0.0673	0.9582		0.0682	1.0434		0.0714	1.0141		0.0682	0.9658	
Mn	0.00238	0.0339	0.1526	0.00154	0.0236	0.3080	0.00122	0.0173	0.2905	0.00111	0.0157	0.7400
Mo	0.000268	0.0038	0.0172	0.000112	0.0017	0.0224	0.000054	0.0008	0.0129	0.000027	0.0004	0.0180
Ne	0.0002	0.0028	0.0128	0.00014	0.0021	0.0280	0.000126	0.0018	0.0300	0.000129	0.0018	0.0860
Nickel	0.00365	0.0520	0.2340	0.0013	0.0199	0.2600	0.000671	0.0095	0.1598	0.000268	0.0038	0.1787
Pr	0.000029	0.0004	0.0019	0.000027	0.0004	0.0054	0.000027	0.0004	0.0064	0.000027	0.0004	0.0180
Ruthenium	0.00002	0.0003	0.0013	0.00002	0.0003	0.0040	0.00002	0.0003	0.0048	0.00002	0.0003	0.0133
Samarium	0.000778	0.0111	0.0499	0.000746	0.0114	0.1492	0.000724	0.0103	0.1724	0.00076	0.0108	0.5067
*Strontium	0.0101	0.1438		0.00981	0.1501		0.0104	0.1477		0.011	0.1558	
Terbium	0.00002	0.0003	0.0013	0.00002	0.0003	0.0040	0.00002	0.0003	0.0048	0.00002	0.0003	0.0133
Titanium	0.00148	0.0211	0.0949	0.0013	0.0199	0.2600	0.00139	0.0197	0.3310	0.00169	0.0239	1.1267
*Zirconium	0.0149	0.2121		0.00928	0.1420		0.0082	0.1165		0.0087	0.1232	
Antimony	0.000848	0.0121	0.0544	0.000474	0.0073	0.0948	0.000563	0.0080	0.1340	0.000429	0.0061	0.2860
Tin	0.00248	0.0353	0.1590	0.00108	0.0165	0.2160	0.000511	0.0073	0.1217	0.0004	0.0057	0.2667
Uranium	0.19	2.7051	12.1795	0.0958	1.4657	19.1600	0.0654	0.9289	15.5714	0.0669	0.9474	44.6000
Others	0.2046	2.9125	13.1135	0.1427	2.1837	28.5464	0.1242	1.7643	29.5757	0.1126	1.5944	75.0607
Sum, mg	7.0238	97.2475	25.7381	6.5361	98.5105	41.7630	7.0407	99.0559	33.5062	7.0618	99.0409	82.5860
mg, Filter Loading	1.560			0.500			0.420			0.150		

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)

NOTE: Species in grey cells are minor impurity contents

Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A3.2A.4 Test 3/2 (A) Marple M1 Elemental Analyses, Stages 4-7

3/2 (A)	STAGE 4			STAGE 5			STAGE 6			STAGE 7		
M1	Particle size 6.0 µm			Particle size 3.5 µm			Particle size 1.55 µm			Particle size 0.93 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	1.43	21.2326		1.92	21.5689		1.57	21.2413		1.41	21.0609	
*Barium	2.71	40.2380		2.94	33.0274		2.86	38.6944		2.7	40.3293	
*Boron	2.36	35.0412		2.6	29.2079		2.5	33.8237		2.4	35.8483	
Cerium	0.00142	0.0211	0.5917	0.00249	0.0280	0.4882	0.000556	0.0075	0.0618	0.000267	0.0040	0.1405
Cesium	0.000016	0.0002	0.0067	0.000026	0.0003	0.0051	0.000018	0.0002	0.0020	0.000015	0.0002	0.0079
Chromium	0.00103	0.0153	0.4292	0.00492	0.0553	0.9647	0.00184	0.0249	0.2044	0.000942	0.0141	0.4958
Copper	0.0138	0.2049	5.7500	0.293	3.2915	57.4510	0.0747	1.0107	8.3000	0.0184	0.2748	9.6842
Europium	0.000449	0.0067	0.1871	0.000525	0.0059	0.1029	0.000505	0.0068	0.0561	0.000478	0.0071	0.2516
Iron	0.0411	0.6103	17.1250	0.293	3.2915	57.4510	0.0935	1.2650	10.3889	0.0352	0.5258	18.5263
La	0.000097	0.0014	0.0404	0.000108	0.0012	0.0212	0.000109	0.0015	0.0121	0.000105	0.0016	0.0553
Lead	0.000798	0.0118	0.3325	0.00304	0.0342	0.5961	0.00132	0.0179	0.1467	0.000761	0.0114	0.4005
Lithium	0.000411	0.0061	0.1713	0.000444	0.0050	0.0871	0.000412	0.0056	0.0458	0.0004	0.0060	0.2105
*Mg	0.0692	1.0275		0.0856	0.9616		0.0766	1.0364		0.0712	1.0635	
Mn	0.00113	0.0168	0.4708	0.00548	0.0616	1.0745	0.00203	0.0275	0.2256	0.00103	0.0154	0.5421
Mo	0.000032	0.0005	0.0133	0.000498	0.0056	0.0976	0.000154	0.0021	0.0171	0.000038	0.0006	0.0200
Ne	0.000129	0.0019	0.0538	0.000143	0.0016	0.0280	0.000115	0.0016	0.0128	0.000113	0.0017	0.0595
Nickel	0.000306	0.0045	0.1275	0.00316	0.0355	0.6196	0.000836	0.0113	0.0929	0.000262	0.0039	0.1379
Pr	0.000026	0.0004	0.0108	0.000028	0.0003	0.0055	0.000027	0.0004	0.0030	0.000027	0.0004	0.0142
Ruthenium	0.00002	0.0003	0.0083	0.00002	0.0002	0.0039	0.00002	0.0003	0.0022	0.00002	0.0003	0.0105
Samarium	0.000695	0.0103	0.2896	0.00083	0.0093	0.1627	0.000787	0.0106	0.0874	0.000743	0.0111	0.3911
*Strontium	0.0102	0.1514		0.0118	0.1326		0.0104	0.1407		0.0101	0.1509	
Terbium	0.00002	0.0003	0.0083	0.00002	0.0002	0.0039	0.00002	0.0003	0.0022	0.00002	0.0003	0.0105
Titanium	0.00165	0.0245	0.6875	0.00185	0.0208	0.3627	0.00163	0.0221	0.1811	0.00128	0.0191	0.6737
*Zirconium	0.00973	0.1445		0.0436	0.4898		0.0144	0.1948		0.00649	0.0969	
Antimony	0.000661	0.0098	0.2754	0.000441	0.0050	0.0865	0.000568	0.0077	0.0631	0.000595	0.0089	0.3132
Tin	0.0004	0.0059	0.1667	0.00967	0.1086	1.8961	0.00271	0.0367	0.3011	0.0004	0.0060	0.2105
Uranium	0.0816	1.2116	34.0000	0.681	7.6502	133.5294	0.178	2.4083	19.7778	0.036	0.5377	18.9474
Others	0.1173	1.7420	48.8846	0.3996	4.4895	78.3614	0.1800	2.4359	20.0046	0.1128	1.6848	59.3653
Sum, mg	6.7349	98.7727	60.7458	8.9017	92.2362	255.0378	7.3913	97.5474	39.9841	6.6949	99.4474	51.1032
mg, Filter Loading	0.240			0.510			0.900			0.190		

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)

NOTE: Species in grey cells are minor impurity contents

Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A3.2A.5 Test 3/2 (A) Marple M1 Elemental Analyses, Stages 8-9

3/2 (A)	STAGE 8			STAGE 9		
M1	Particle size 0.52 µm			Particle size final, <0.5 µm		
	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	1.3	19.1927		1.43	19.5226	
*Barium	2.81	41.4857		3.08	42.0488	
*Boron	2.47	36.4660		2.67	36.4514	
Cerium	0.00025	0.0037	0.1563	0.000279	0.0038	
Cesium	0.000023	0.0003	0.0144	0.000023	0.0003	
Chromium	0.000938	0.0138	0.5863	0.000744	0.0102	
Copper	0.024	0.3543	15.0000	0.00445	0.0608	
Europium	0.00042	0.0062	0.2625	0.000539	0.0074	
Iron	0.0331	0.4887	20.6875	0.0241	0.3290	
La	0.000091	0.0013	0.0569	0.000132	0.0018	
Lead	0.000765	0.0113	0.4781	0.000868	0.0119	
Lithium	0.000394	0.0058	0.2463	0.000464	0.0063	
*Mg	0.0662	0.9773		0.084	1.1468	
Mn	0.000957	0.0141	0.5981	0.000883	0.0121	
Mo	0.000049	0.0007	0.0306	0.000018	0.0002	
Ne	0.000099	0.0015	0.0619	0.000143	0.0020	
Nickel	0.000247	0.0036	0.1544	0.00011	0.0015	
Pr	0.000023	0.0003	0.0144	0.000034	0.0005	
Ruthenium	0.00002	0.0003	0.0125	0.00002	0.0003	
Samarium	0.000653	0.0096	0.4081	0.00085	0.0116	
*Strontium	0.00994	0.1467		0.0117	0.1597	
Terbium	0.00002	0.0003	0.0125	0.00002	0.0003	
Titanium	0.00152	0.0224	0.9500	0.00158	0.0216	
*Zirconium	0.00798	0.1178		0.00674	0.0920	
Antimony	0.00049	0.0072	0.3063	0.000453	0.0062	
Tin	0.000447	0.0066	0.2794	0.0004	0.0055	
Uranium	0.0448	0.6614	28.0000	0.00628	0.0857	
Others	0.1056	1.5586	65.9825	0.1145	1.5628	
Sum, mg	6.7734	99.3248	68.3163	7.3248	99.9026	0.0000
mg, Metals Found	0.160			-3.900		

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)
NOTE: Species in grey cells are minor impurity contents
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A3.2A.6 Test 3/2 (A) LPS L1 Elemental Analyses

	Segment 0		Segment 1		Segment 2		Segment 3		Segment 4	
3/2 (A)	post swipe		~82-100 µm		~65-82 µm		~48-65 µm		~30-48 µm	
L1	mg	% detect	mg	% detect	mg	% detect	mg	% detect	mg	% detect
*Aluminum	0.01	4.2326	0.808	23.8579	0.843	24.7065	0.68	24.0232	0.754	23.3807
*Barium	0.0072	3.0475	1.34	39.5664	1.33	38.9795	1.09	38.5078	1.23	38.1410
*Boron	0.0199	8.4230	1.15	33.9562	1.16	33.9971	0.962	33.9858	1.09	33.7997
Cerium	0.00655	2.7724	0.00108	0.0319	0.000643	0.0188	0.00129	0.0456	0.00197	0.0611
Cesium	0.000285	0.1206	0.000022	0.0006	0.00001	0.0003	0.00001	0.0004	0.000018	0.0006
Chromium	0.00545	2.3068	0.00153	0.0452	0.000624	0.0183	0.000738	0.0261	0.00184	0.0571
Copper	0.0221	9.3541	0.00458	0.1352	0.00286	0.0838	0.00317	0.1120	0.00766	0.2375
Europium	0.000042	0.0178	0.000229	0.0068	0.000224	0.0066	0.000185	0.0065	0.000211	0.0065
Iron	0.0665	28.1471	0.0208	0.6142	0.0154	0.4513	0.0175	0.6182	0.0251	0.7783
La	0.000109	0.0461	0.00006	0.0018	0.000051	0.0015	0.000046	0.0016	0.000055	0.0017
Lead	0.000145	0.0614	0.000431	0.0127	0.000415	0.0122	0.000364	0.0129	0.000394	0.0122
Lithium	0.0002	0.0847	0.000195	0.0058	0.000183	0.0054	0.00015	0.0053	0.000165	0.0051
*Mg	0.0338	14.3063	0.0321	0.9478	0.0336	0.9847	0.0248	0.8761	0.0288	0.8931
Mn	0.0128	5.4178	0.000453	0.0134	0.000382	0.0112	0.000373	0.0132	0.000588	0.0182
Mo	0.000181	0.0766	0.000041	0.0012	0.000012	0.0004	0.000018	0.0006	0.000032	0.0010
Ne	0.000195	0.0825	0.000078	0.0023	0.000065	0.0019	0.000075	0.0026	0.000089	0.0028
Nickel	0.00391	1.6550	0.000695	0.0205	0.000147	0.0043	0.000236	0.0083	0.000943	0.0292
Pr	0.00002	0.0085	0.00002	0.0006	0.00002	0.0006	0.00002	0.0007	0.00002	0.0006
Ruthenium	0.000039	0.0165	0.00002	0.0006	0.00002	0.0006	0.00002	0.0007	0.00002	0.0006
Samarium	0.00002	0.0085	0.000351	0.0104	0.000343	0.0101	0.000289	0.0102	0.000319	0.0099
*Strontium	0.00155	0.6561	0.00607	0.1792	0.00598	0.1753	0.00482	0.1703	0.00539	0.1671
Terbium	0.00002	0.0085	0.00002	0.0006	0.00002	0.0006	0.00002	0.0007	0.00002	0.0006
Titanium	0.000343	0.1452	0.000839	0.0248	0.000723	0.0212	0.000719	0.0254	0.000814	0.0252
*Zirconium	0.0032	1.3544	0.003	0.0886	0.00263	0.0771	0.00355	0.1254	0.00313	0.0971
Antimony	0.0004	0.1693	0.0004	0.0118	0.0004	0.0117	0.0004	0.0141	0.000401	0.0124
Tin	0.0004	0.1693	0.0004	0.0118	0.0004	0.0117	0.0004	0.0141	0.0004	0.0124
Uranium	0.0409	17.3115	0.0153	0.4518	0.0139	0.4074	0.0394	1.3919	0.0725	2.2481
Others	0.1239	52.4573	0.0580	1.7140	0.0524	1.5365	0.0458	1.6174	0.0596	1.8489
Sum, mg	0.2363	82.3499	3.3867	99.5246	3.4121	99.5692	2.8306	98.5798	3.2249	97.7270
mg, Filter Loading										

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)
NOTE: Species in grey cells are minor impurity contents
Others: Sb, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Sm, Tb, Ti

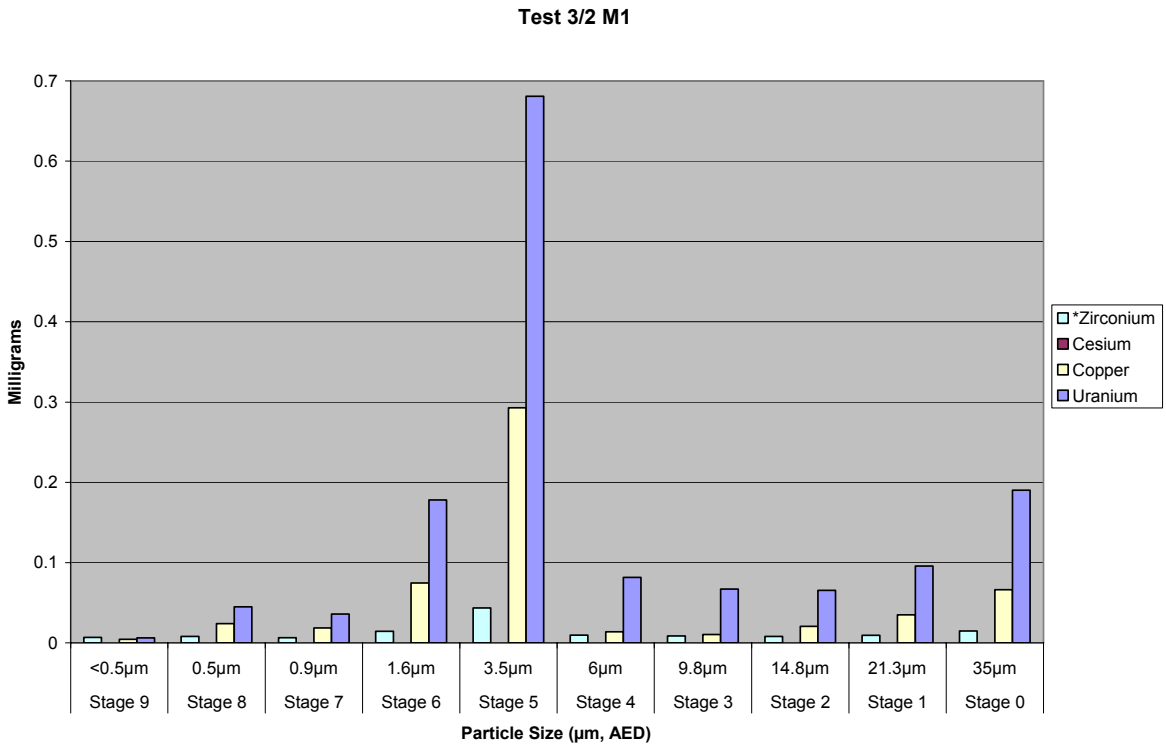


Figure A3.2A.7 Test 3/2 (A) Marple M1 Metals Analysis Distribution, mg

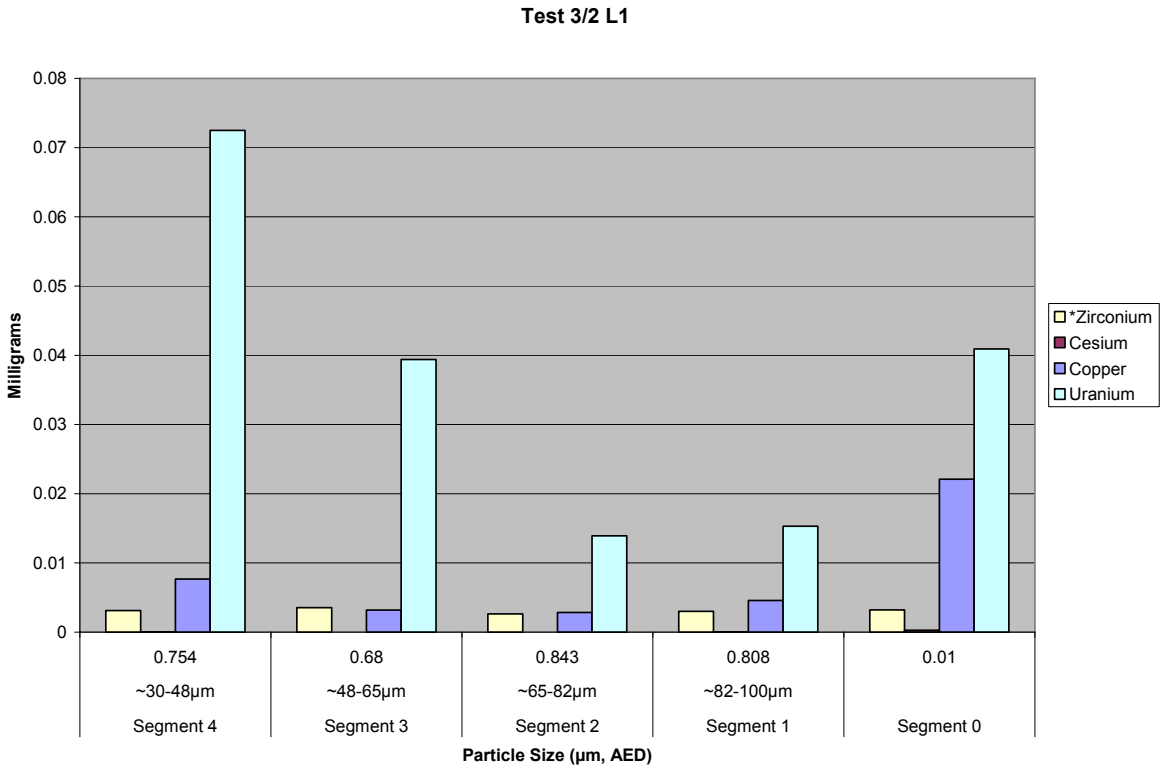


Figure A3.2A.8 Test 3/2 (A) LPS L1 Metals Analysis Distribution, mg

Table A3.2A.7 Test 3/2 (A) Marple M2 Elemental Analyses, Stages 0-3

3/2 (A)	STAGE 0			STAGE 1			STAGE 2			STAGE 3		
M2	Particle size 35 µm			Particle size 21.3 µm			Particle size 14.8 µm			Particle size 9.8 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	1.5	21.1259		1.35	17.0581		1.34	17.7986		1.36	20.3933	
*Barium	2.88	40.5618		4.05	51.1744		2.81	37.3240		2.76	41.3865	
*Boron	2.42	34.0832		2.34	29.5674		3.21	42.6370		2.42	36.2881	
Cerium	0.00405	0.0570	0.2213	0.0017	0.0215	0.6800	0.000602	0.0080	0.3010	0.000387	0.0058	0.0766
Cesium	0.00006	0.0008	0.0033	0.000026	0.0003	0.0104	0.000019	0.0003	0.0095	0.000014	0.0002	0.0028
Chromium	0.00215	0.0303	0.1175	0.001	0.0126	0.4000	0.000984	0.0131	0.4920	0.000753	0.0113	0.1491
Copper	0.0368	0.5183	2.0109	0.0159	0.2009	6.3600	0.0131	0.1740	6.5500	0.0039	0.0585	0.7723
Europium	0.000526	0.0074	0.0287	0.000438	0.0055	0.1752	0.000487	0.0065	0.2435	0.000435	0.0065	0.0861
Iron	0.0633	0.8915	3.4590	0.0362	0.4574	14.4800	0.0341	0.4529	17.0500	0.0246	0.3689	4.8713
La	0.000123	0.0017	0.0067	0.0001	0.0013	0.0400	0.000107	0.0014	0.0535	0.000099	0.0015	0.0196
Lead	0.00113	0.0159	0.0617	0.000772	0.0098	0.3088	0.000833	0.0111	0.4165	0.000605	0.0091	0.1198
Lithium	0.000415	0.0058	0.0227	0.000382	0.0048	0.1528	0.000384	0.0051	0.1920	0.000388	0.0058	0.0768
*Mg	0.0737	1.0380		0.0652	0.8238		0.0676	0.8979		0.0715	1.0721	
Mn	0.0015	0.0211	0.0820	0.000982	0.0124	0.3928	0.000956	0.0127	0.4780	0.000808	0.0121	0.1600
Mo	0.000141	0.0020	0.0077	0.000053	0.0007	0.0212	0.000038	0.0005	0.0190	0.000014	0.0002	0.0028
Ne	0.000192	0.0027	0.0105	0.00012	0.0015	0.0480	0.000115	0.0015	0.0575	0.000107	0.0016	0.0212
Nickel	0.00114	0.0161	0.0623	0.000343	0.0043	0.1372	0.000332	0.0044	0.1660	0.000168	0.0025	0.0333
Pr	0.00003	0.0004	0.0016	0.000026	0.0003	0.0104	0.000027	0.0004	0.0135	0.000025	0.0004	0.0050
Ruthenium	0.00002	0.0003	0.0011	0.00002	0.0003	0.0080	0.00002	0.0003	0.0100	0.00002	0.0003	0.0040
Samarium	0.000794	0.0112	0.0434	0.000668	0.0084	0.2672	0.000762	0.0101	0.3810	0.000681	0.0102	0.1349
*Strontium	0.0102	0.1437		0.00954	0.1205		0.00971	0.1290		0.0102	0.1530	
Terbium	0.00002	0.0003	0.0011	0.00002	0.0003	0.0080	0.00002	0.0003	0.0100	0.00002	0.0003	0.0040
Titanium	0.00137	0.0193	0.0749	0.00144	0.0182	0.5760	0.0014	0.0186	0.7000	0.00149	0.0223	0.2950
*Zirconium	0.00888	0.1251		0.00626	0.0791		0.00572	0.0760		0.00514	0.0771	
Antimony	0.000463	0.0065	0.0253	0.000428	0.0054	0.1712	0.000554	0.0074	0.2770	0.0004	0.0060	0.0792
Tin	0.00107	0.0151	0.0585	0.0004	0.0051	0.1600	0.0004	0.0053	0.2000	0.0004	0.0060	0.0792
Uranium	0.0922	1.2985	5.0383	0.0321	0.4056	12.8400	0.0304	0.4038	15.2000	0.00669	0.1003	1.3248
Others	0.1466	2.0644	8.0098	0.1078	1.3620	43.1160	0.1083	1.4387	54.1575	0.1017	1.5251	20.1396
Sum, mg	7.1003	100.0000	11.3385	7.9141	100.0000	37.2472	7.5287	100.0000	42.8200	6.6688	100.0000	8.3176
mg, Filter Loading	1.8300			0.2500			0.2000			0.5050		

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)
NOTE: Species in grey cells are minor impurity contents
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A3.2A.8 Test 3/2 (A) Marple M2 Elemental Analyses, Stages 4-7

3/2 (A)	STAGE 4			STAGE 5			STAGE 6			STAGE 7		
M2	Particle size 6.0 µm			Particle size 3.5 µm			Particle size 1.55 µm			Particle size 0.93 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	1.32	20.7080		2.18	19.3234		1.51	23.2042		1.61	22.5206	
*Barium	2.68	42.0435		4.7	41.6605		2.51	38.5713		2.84	39.7257	
*Boron	2.24	35.1408		3.87	34.3034		2.14	32.8855		2.34	32.7317	
Cerium	0.00038	0.0060	0.9500	0.00095	0.0084	0.1532	0.00041	0.0063	0.0641	0.00042	0.0059	0.0840
Cesium	0.000014	0.0002	0.0350	0.000023	0.0002	0.0037	0.000012	0.0002	0.0019	0.000014	0.0002	0.0028
Chromium	0.000778	0.0122	1.9450	0.00209	0.0185	0.3371	0.00161	0.0247	0.2516	0.00162	0.0227	0.3240
Copper	0.00641	0.1006	16.0250	0.0772	0.6843	12.4516	0.0521	0.8006	8.1406	0.0563	0.7875	11.2600
Europium	0.000466	0.0073	1.1650	0.000816	0.0072	0.1316	0.000396	0.0061	0.0619	0.000464	0.0065	0.0928
Iron	0.0271	0.4251	67.7500	0.108	0.9573	17.4194	0.0696	1.0695	10.8750	0.0699	0.9778	13.9800
La	0.000105	0.0016	0.2625	0.000171	0.0015	0.0276	0.000093	0.0014	0.0145	0.000102	0.0014	0.0204
Lead	0.000612	0.0096	1.5300	0.00167	0.0148	0.2694	0.00104	0.0160	0.1625	0.00111	0.0155	0.2220
Lithium	0.000384	0.0060	0.9600	0.000659	0.0058	0.1063	0.000383	0.0059	0.0598	0.000403	0.0056	0.0806
*Mg	0.067	1.0511		0.123	1.0903		0.0773	1.1879		0.0765	1.0701	
Mn	0.000836	0.0131	2.0900	0.00242	0.0215	0.3903	0.00169	0.0260	0.2641	0.00169	0.0236	0.3380
Mo	0.000018	0.0003	0.0450	0.000366	0.0032	0.0590	0.000106	0.0016	0.0166	0.000108	0.0015	0.0216
Ne	0.00011	0.0017	0.2750	0.00019	0.0017	0.0306	0.000104	0.0016	0.0163	0.000113	0.0016	0.0226
Nickel	0.000208	0.0033	0.5200	0.00094	0.0083	0.1516	0.000644	0.0099	0.1006	0.000625	0.0087	0.1250
Pr	0.000027	0.0004	0.0675	0.000043	0.0004	0.0069	0.000024	0.0004	0.0038	0.000026	0.0004	0.0052
Ruthenium	0.00002	0.0003	0.0500	0.00002	0.0002	0.0032	0.00002	0.0003	0.0031	0.00002	0.0003	0.0040
Samarium	0.000724	0.0114	1.8100	0.00128	0.0113	0.2065	0.000618	0.0095	0.0966	0.000719	0.0101	0.1438
*Strontium	0.00959	0.1504		0.0179	0.1587		0.00978	0.1503		0.0103	0.1441	
Terbium	0.00002	0.0003	0.0500	0.00002	0.0002	0.0032	0.00002	0.0003	0.0031	0.00002	0.0003	0.0040
Titanium	0.00118	0.0185	2.9500	0.00219	0.0194	0.3532	0.00122	0.0187	0.1906	0.00138	0.0193	0.2760
*Zirconium	0.00489	0.0767		0.0174	0.1542		0.0105	0.1614		0.0115	0.1609	
Antimony	0.000678	0.0106	1.6950	0.000792	0.0070	0.1277	0.0004	0.0061	0.0625	0.0004	0.0056	0.0800
Tin	0.0004	0.0063	1.0000	0.00253	0.0224	0.4081	0.00136	0.0209	0.2125	0.00129	0.0180	0.2580
Uranium	0.0124	0.1945	31.0000	0.171	1.5157	27.5806	0.118	1.8133	18.4375	0.124	1.7345	24.8000
Others	0.0999	1.5666	249.6550	0.2440	2.1627	39.3529	0.1549	2.3798	24.1977	0.1548	2.1650	30.9554
Sum, mg	6.3744	100.0000	132.1750	11.2817	100.0000	60.2210	6.5074	100.0000	39.0391	7.1490	100.0000	52.1448
mg, Filter Loading	0.0400			0.6200			0.6400			0.5000		

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)
NOTE: Species in grey cells are minor impurity contents
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A3.2A.9 Test 3/2 (A) Marple M2 Elemental Analyses, Stages 8-9

3/2 (A)	STAGE 8			STAGE 9		
M2	Particle size 0.52 µm			Particle size final, <0.5 µm		
	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	1.44	22.7674		1.68	24.3140	
*Barium	2.48	39.2106		2.72	39.3656	
*Boron	2.29	36.2065		2.38	34.4449	
Cerium	0.00021	0.0033	0.0808	0.000265	0.0038	0.2409
Cesium	0.000014	0.0002	0.0054	0.000014	0.0002	0.0127
Chromium	0.000805	0.0127	0.3096	0.000928	0.0134	0.8436
Copper	0.00149	0.0236	0.5731	0.000801	0.0116	0.7282
Europium	0.000431	0.0068	0.1658	0.000469	0.0068	0.4264
Iron	0.019	0.3004	7.3077	0.0231	0.3343	21.0000
La	0.0001	0.0016	0.0385	0.00013	0.0019	0.1182
Lead	0.000603	0.0095	0.2319	0.000755	0.0109	0.6864
Lithium	0.000371	0.0059	0.1427	0.00041	0.0059	0.3727
*Mg	0.0741	1.1716		0.0853	1.2345	
Mn	0.000785	0.0124	0.3019	0.000893	0.0129	0.8118
Mo	0.00001	0.0002	0.0038	0.00001	0.0001	0.0091
Ne	0.000107	0.0017	0.0412	0.000145	0.0021	0.1318
Nickel	0.00014	0.0022	0.0538	0.000108	0.0016	0.0982
Pr	0.000026	0.0004	0.0100	0.000035	0.0005	0.0318
Ruthenium	0.00002	0.0003	0.0077	0.00002	0.0003	0.0182
Samarium	0.000672	0.0106	0.2585	0.000722	0.0104	0.6564
*Strontium	0.00948	0.1499		0.00999	0.1446	
Terbium	0.00002	0.0003	0.0077	0.00002	0.0003	0.0182
Titanium	0.00106	0.0168	0.4077	0.000833	0.0121	0.7573
*Zirconium	0.00377	0.0596		0.0036	0.0521	
Antimony	0.0004	0.0063	0.1538	0.0004	0.0058	0.3636
Tin	0.0004	0.0063	0.1538	0.0004	0.0058	0.3636
Uranium	0.000809	0.0128	0.3112	0.000241	0.0035	0.2191
Others	0.0983	1.5535	37.7919	0.1138	1.6477	103.4982
Sum, mg	6.3248	100.0000	10.5665	6.9096	100.0000	27.9082
mg, Metals Found	0.2600			0.1100		

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)
NOTE: Species in grey cells are minor impurity contents
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A3.2A.10 Test 3/2 (A) LPS L2 Elemental Analyses

	Segment 0		Segment 1		Segment 2		Segment 3		Segment 4	
3/2 (A)	post swipe		~82-100 µm		~65-82 µm		~48-65 µm		~30-48 µm	
L2	mg	% detect	mg	% detect	mg	% detect	mg	% detect	mg	% detect
*Aluminum	0.0138	7.2547	0.744	25.3890	0.764	26.1240	0.899	26.8437	0.895	26.1983
*Barium	0.00479	2.5181	1.12	38.2201	1.14	38.9808	1.32	39.4145	1.25	36.5898
*Boron	0.00432	2.2710	0.995	33.9544	0.961	32.8601	1.06	31.6510	1.07	31.3208
Cerium	0.00136	0.7150	0.000918	0.0313	0.000313	0.0107	0.000622	0.0186	0.00091	0.0266
Cesium	0.000153	0.0804	0.000012	0.0004	0.000012	0.0004	0.000012	0.0004	0.000013	0.0004
Chromium	0.00255	1.3405	0.000706	0.0241	0.000602	0.0206	0.000647	0.0193	0.00118	0.0345
Copper	0.0137	7.2021	0.00305	0.1041	0.00206	0.0704	0.00309	0.0923	0.0295	0.8635
Europium	0.00002	0.0105	0.000184	0.0063	0.000186	0.0064	0.00022	0.0066	0.000215	0.0063
Iron	0.033	17.3482	0.0114	0.3890	0.00943	0.3224	0.0131	0.3912	0.0424	1.2411
La	0.000033	0.0173	0.000046	0.0016	0.000047	0.0016	0.000053	0.0016	0.000051	0.0015
Lead	0.000412	0.2166	0.000318	0.0109	0.000331	0.0113	0.000394	0.0118	0.000645	0.0189
Lithium	0.0002	0.1051	0.0002	0.0068	0.0002	0.0068	0.0002	0.0060	0.0002	0.0059
*Mg	0.0308	16.1916	0.0286	0.9760	0.0295	1.0087	0.0346	1.0331	0.0341	0.9982
Mn	0.0327	17.1904	0.000344	0.0117	0.000318	0.0109	0.000384	0.0115	0.000905	0.0265
Mo	0.000088	0.0463	0.000016	0.0005	0.00001	0.0003	0.000011	0.0003	0.000062	0.0018
Ne	0.000034	0.0179	0.000064	0.0022	0.000056	0.0019	0.000075	0.0022	0.000071	0.0021
Nickel	0.00161	0.8464	0.000119	0.0041	0.000066	0.0023	0.000079	0.0024	0.00042	0.0123
Pr	0.00002	0.0105	0.00002	0.0007	0.00002	0.0007	0.00002	0.0006	0.00002	0.0006
Ruthenium	0.00002	0.0105	0.00002	0.0007	0.00002	0.0007	0.00002	0.0006	0.00002	0.0006
Samarium	0.00002	0.0105	0.000284	0.0097	0.000289	0.0099	0.000341	0.0102	0.00033	0.0097
*Strontium	0.00105	0.5520	0.00481	0.1641	0.0049	0.1675	0.0058	0.1732	0.0056	0.1639
Terbium	0.00002	0.0105	0.00002	0.0007	0.00002	0.0007	0.00002	0.0006	0.00002	0.0006
Titanium	0.000328	0.1724	0.000617	0.0211	0.000536	0.0183	0.000573	0.0171	0.000563	0.0165
*Zirconium	0.0024	1.2617	0.00235	0.0802	0.00189	0.0646	0.00203	0.0606	0.00581	0.1701
Antimony	0.000494	0.2597	0.0004	0.0137	0.0004	0.0137	0.0004	0.0119	0.0004	0.0117
Tin	0.0004	0.2103	0.0004	0.0137	0.0004	0.0137	0.0004	0.0119	0.00122	0.0357
Uranium	0.0459	24.1297	0.0165	0.5631	0.00791	0.2705	0.00693	0.2069	0.0766	2.2422
Others	0.1021	53.6894	0.0431	1.4721	0.0418	1.4297	0.0509	1.5204	0.0814	2.3822
Sum, mg	0.1902	100.0000	2.9304	100.0000	2.9245	100.0000	3.3490	100.0000	3.4163	100.0000
mg, Filter Loading										

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)
NOTE: Species in grey cells are minor impurity contents
Others: Sb, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Sm, Tb, Ti

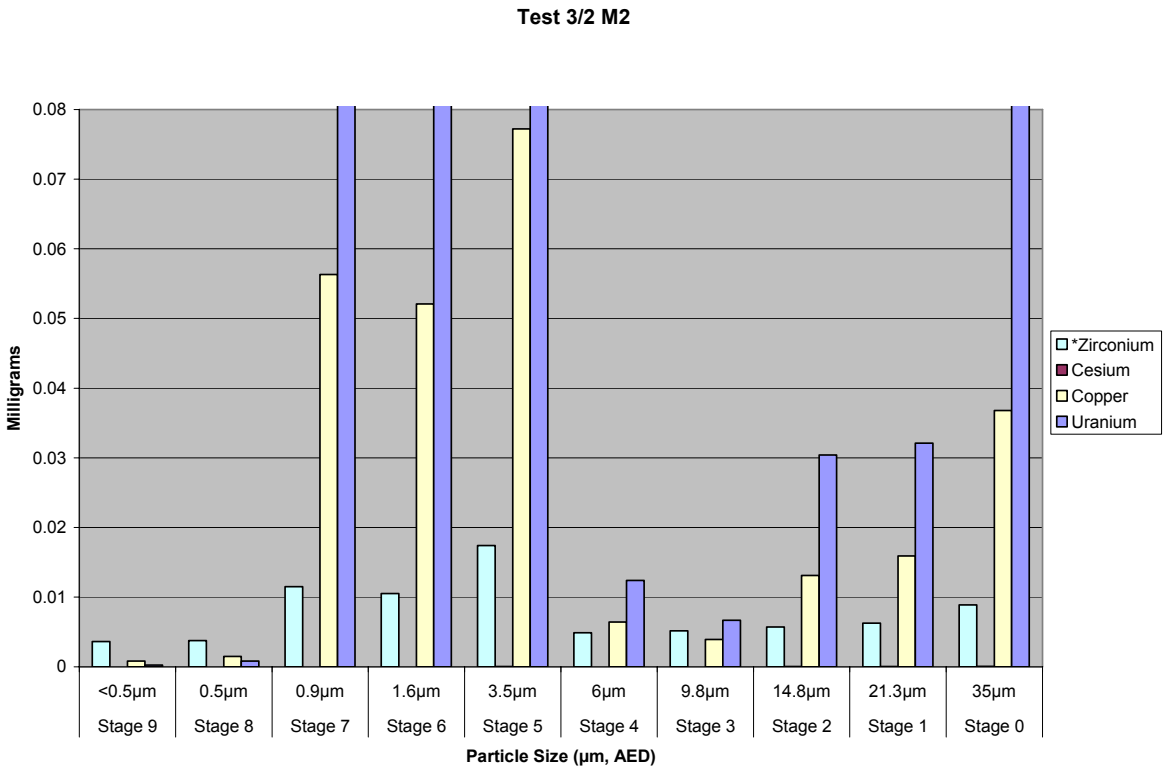


Figure A3.2A.9 Test 3/2 (A) Marple M2 Metals Analysis Distribution, mg

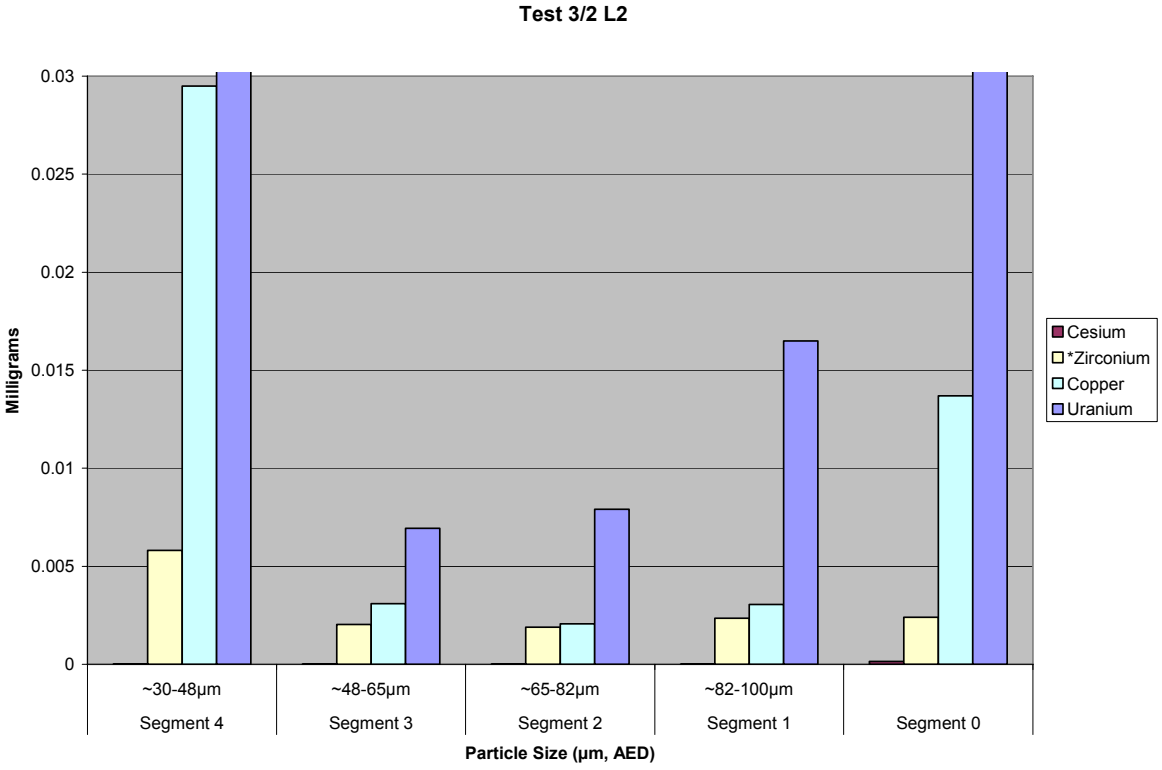


Figure A3.2A.10 Test 3/2 (A) LPS L2 Metals Analysis Distribution, mg

Table A3.2A.11 Test 3/2 (A) Marple M3 Elemental Analyses, Stages 0-3

3/2 (A)	STAGE 0			STAGE 1			STAGE 2			STAGE 3		
M3	Particle size 35 μm			Particle size 21.3 μm			Particle size 14.8 μm			Particle size 9.8 μm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	1.47	22.8489		1.56	23.6640		1.51	22.9109		1.19	21.4918	
*Barium	2.62	40.7239		2.66	40.3501		2.65	40.2079		2.22	40.0939	
*Boron	2.22	34.5065		2.25	34.1307		2.31	35.0491		2.03	36.6624	
Cerium	0.000228	0.0035	0.0036	0.000222	0.0034	0.4440	0.000207	0.0031		0.00021	0.0038	
Cesium	0.000016	0.0002	0.0003	0.000014	0.0002	0.0280	0.000015	0.0002		0.000013	0.0002	
Chromium	0.000898	0.0140	0.0141	0.000884	0.0134	1.7680	0.000867	0.0132		0.000701	0.0127	
Copper	0.00433	0.0673	0.0678	0.00211	0.0320	4.2200	0.000712	0.0108		0.00061	0.0110	
Europium	0.000432	0.0067	0.0068	0.000437	0.0066	0.8740	0.000469	0.0071		0.000371	0.0067	
Iron	0.0187	0.2907	0.2926	0.0196	0.2973	39.2000	0.0194	0.2944		0.0158	0.2854	
La	0.000104	0.0016	0.0016	0.000098	0.0015	0.1960	0.000102	0.0015		0.00009	0.0016	
Lead	0.000604	0.0094	0.0095	0.000615	0.0093	1.2300	0.000617	0.0094		0.000528	0.0095	
Lithium	0.000409	0.0064	0.0064	0.000387	0.0059	0.7740	0.000408	0.0062		0.00031	0.0056	
*Mg	0.0758	1.1782		0.0736	1.1165		0.0795	1.2062		0.0628	1.1342	
Mn	0.000826	0.0128	0.0129	0.000862	0.0131	1.7240	0.000839	0.0127		0.000668	0.0121	
Mo	0.000013	0.0002	0.0002	0.000012	0.0002	0.0240	0.00001	0.0002		0.00001	0.0002	
Ne	0.000109	0.0017	0.0017	0.000104	0.0016	0.2080	0.000112	0.0017		0.000095	0.0017	
Nickel	0.000212	0.0033	0.0033	0.00482	0.0731	9.6400	0.000201	0.0030		0.000105	0.0019	
Pr	0.000026	0.0004	0.0004	0.000025	0.0004	0.0500	0.000026	0.0004		0.000023	0.0004	
Ruthenium	0.00002	0.0003	0.0003	0.00002	0.0003	0.0400	0.00002	0.0003		0.00002	0.0004	
Samarium	0.000678	0.0105	0.0106	0.000677	0.0103	1.3540	0.000727	0.0110		0.00058	0.0105	
*Strontium	0.00999	0.1553		0.00999	0.1515		0.0104	0.1578		0.00817	0.1476	
Terbium	0.00002	0.0003	0.0003	0.00002	0.0003	0.0400	0.00002	0.0003		0.00002	0.0004	
Titanium	0.00105	0.0163	0.0164	0.00123	0.0187	2.4600	0.00122	0.0185		0.00111	0.0200	
*Zirconium	0.00411	0.0639		0.0041	0.0622		0.00385	0.0584		0.00381	0.0688	
Antimony	0.0004	0.0062	0.0063	0.0004	0.0061	0.8000	0.0004	0.0061		0.0004	0.0072	
Tin	0.0004	0.0062	0.0063	0.0004	0.0061	0.8000	0.0004	0.0061		0.0004	0.0072	
Uranium	0.00419	0.0651	0.0656	0.00167	0.0253	3.3400	0.000224	0.0034		0.000161	0.0029	
Others	0.0999	1.5524	1.5629	0.1034	1.5683	206.7680	0.1045	1.5857		0.0833	1.5044	
Sum, mg	6.4336	100.0000	0.5268	6.5923	100.0000	69.2140	6.5907	100.0000	0.0000	5.5370	100.0000	0.0000
mg, Filter Loading	6.3900			0.0500			-0.0800			-0.1300		

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)
NOTE: Species in grey cells are minor impurity contents
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A3.2A.12 Test 3/2 (A) Marple M3 Elemental Analyses, Stages 4-7

3/2 (A)	STAGE 4			STAGE 5			STAGE 6			STAGE 7		
M3	Particle size 6.0 µm			Particle size 3.5 µm			Particle size 1.55 µm			Particle size 0.93 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	1.4	24.1973		1.55	24.1773		1.43	23.2670		1.48	22.5065	
*Barium	2.24	38.7157		2.48	38.6836		2.46	40.0257		2.68	40.7550	
*Boron	2.04	35.2590		2.27	35.4080		2.15	34.9818		2.3	34.9763	
Cerium	0.000231	0.0040		0.000228	0.0036		0.000191	0.0031		0.000219	0.0033	
Cesium	0.000013	0.0002		0.000014	0.0002		0.000017	0.0003		0.000014	0.0002	
Chromium	0.000799	0.0138		0.000835	0.0130		0.000854	0.0139		0.000875	0.0133	
Copper	0.000735	0.0127		0.000888	0.0139		0.00112	0.0182		0.00127	0.0193	
Europium	0.000404	0.0070		0.000426	0.0066		0.000411	0.0067		0.000435	0.0066	
Iron	0.0174	0.3007		0.0185	0.2886		0.0178	0.2896		0.0199	0.3026	
La	0.000093	0.0016		0.000096	0.0015		0.000092	0.0015		0.000102	0.0016	
Lead	0.000557	0.0096		0.000572	0.0089		0.000541	0.0088		0.000574	0.0087	
Lithium	0.000354	0.0061		0.000372	0.0058		0.000351	0.0057		0.000364	0.0055	
*Mg	0.0686	1.1857		0.0717	1.1184		0.0685	1.1145		0.0748	1.1375	
Mn	0.000769	0.0133		0.000772	0.0120		0.000747	0.0122		0.000787	0.0120	
Mo	0.00001	0.0002		0.00001	0.0002		0.000012	0.0002		0.00001	0.0002	
Ne	0.000101	0.0017		0.000102	0.0016		0.000099	0.0016		0.000108	0.0016	
Nickel	0.000989	0.0171		0.000171	0.0027		0.000284	0.0046		0.000457	0.0069	
Pr	0.000025	0.0004		0.000025	0.0004		0.000024	0.0004		0.000027	0.0004	
Ruthenium	0.00002	0.0003		0.00002	0.0003		0.00002	0.0003		0.00002	0.0003	
Samarium	0.000628	0.0109		0.000664	0.0104		0.000646	0.0105		0.000678	0.0103	
*Strontium	0.00902	0.1559		0.00961	0.1499		0.009	0.1464		0.00947	0.1440	
Terbium	0.00002	0.0003		0.00002	0.0003		0.00002	0.0003		0.00002	0.0003	
Titanium	0.000881	0.0152		0.00121	0.0189		0.00087	0.0142		0.000968	0.0147	
*Zirconium	0.00312	0.0539		0.00364	0.0568		0.00308	0.0501		0.00336	0.0511	
Antimony	0.0004	0.0069		0.0004	0.0062		0.0004	0.0065		0.0004	0.0061	
Tin	0.0004	0.0069		0.0004	0.0062		0.0004	0.0065		0.0004	0.0061	
Uranium	0.000191	0.0033		0.000303	0.0047		0.000574	0.0093		0.00063	0.0096	
Others	0.0917	1.5845		0.0955	1.4897		0.0913	1.4855		0.1001	1.5229	
Sum, mg	5.7858	100.0000	0.0000	6.4110	100.0000	0.0000	6.1461	100.0000	0.0000	6.5759	100.0000	0.0000
mg, Filter Loading	-0.3700			-0.0300			-0.0900			-0.3300		

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)

NOTE: Species in grey cells are minor impurity contents

Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A3.2A.13 Test 3/2 (A) Marple M3 Elemental Analyses, Stages 8-9

3/2 (A)	STAGE 8			STAGE 9		
M3	Particle size 0.52 µm			Particle size final, <0.5 µm		
	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	1.44	22.7674		1.68	24.3140	
*Barium	2.48	39.2106		2.72	39.3656	
*Boron	2.29	36.2065		2.38	34.4449	
Cerium	0.00021	0.0033		0.000265	0.0038	
Cesium	0.000014	0.0002		0.000014	0.0002	
Chromium	0.000805	0.0127		0.000928	0.0134	
Copper	0.00149	0.0236		0.000801	0.0116	
Europium	0.000431	0.0068		0.000469	0.0068	
Iron	0.019	0.3004		0.0231	0.3343	
La	0.0001	0.0016		0.00013	0.0019	
Lead	0.000603	0.0095		0.000755	0.0109	
Lithium	0.000371	0.0059		0.00041	0.0059	
*Mg	0.0741	1.1716		0.0853	1.2345	
Mn	0.000785	0.0124		0.000893	0.0129	
Mo	0.00001	0.0002		0.00001	0.0001	
Ne	0.000107	0.0017		0.000145	0.0021	
Nickel	0.00014	0.0022		0.000108	0.0016	
Pr	0.000026	0.0004		0.000035	0.0005	
Ruthenium	0.00002	0.0003		0.00002	0.0003	
Samarium	0.000672	0.0106		0.000722	0.0104	
*Strontium	0.00948	0.1499		0.00999	0.1446	
Terbium	0.00002	0.0003		0.00002	0.0003	
Titanium	0.00106	0.0168		0.000833	0.0121	
*Zirconium	0.00377	0.0596		0.0036	0.0521	
Antimony	0.0004	0.0063		0.0004	0.0058	
Tin	0.0004	0.0063		0.0004	0.0058	
Uranium	0.000809	0.0128		0.000241	0.0035	
Others	0.0983	1.5535		0.1138	1.6477	
Sum, mg	6.3248	100.0000	0.0000	6.9096	100.0000	0.0000
mg, Filter Loading	-0.2100			-0.0700		

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)
NOTE: Species in grey cells are minor impurity contents
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A3.2A.14 Test 3/2 (A) LPS L3 Elemental Analyses

	Segment 0		Segment 1		Segment 2		Segment 3		Segment 4	
3/2 (A)	post swipe		~82-100 µm		~65-82 µm		~48-65 µm		~30-48 µm	
L3	mg	% detect	mg	% detect	mg	% detect	mg	% detect	mg	% detect
*Aluminum	0.0111	1.9446	0.724	24.7439	0.771	25.1773	0.88	25.5708	0.847	25.7862
*Barium	0.105	18.3949	1.15	39.3032	1.21	39.5130	1.45	42.1337	1.4	42.6219
*Boron	0.00318	0.5571	1	34.1767	1.03	33.6350	1.05	30.5106	0.974	29.6526
Cerium	0.00369	0.6464	0.000937	0.0320	0.000167	0.0055	0.000136	0.0040	0.000586	0.0178
Cesium	0.000068	0.0119	0.000107	0.0037	0.00001	0.0003	0.00001	0.0003	0.000124	0.0038
Chromium	0.00364	0.6377	0.000614	0.0210	0.000595	0.0194	0.000596	0.0173	0.000616	0.0188
Copper	0.0142	2.4877	0.0026	0.0889	0.000751	0.0245	0.000733	0.0213	0.0029	0.0883
Europium	0.000054	0.0095	0.000194	0.0066	0.000204	0.0067	0.00019	0.0055	0.000207	0.0063
Iron	0.374	65.5208	0.01	0.3418	0.00922	0.3011	0.0117	0.3400	0.0119	0.3623
La	0.000104	0.0182	0.000054	0.0018	0.000049	0.0016	0.00005	0.0015	0.000058	0.0018
Lead	0.000358	0.0627	0.000316	0.0108	0.00033	0.0108	0.000371	0.0108	0.000385	0.0117
Lithium	0.0002	0.0350	0.0002	0.0068	0.0002	0.0065	0.0002	0.0058	0.0002	0.0061
*Mg	0.0228	3.9943	0.0279	0.9535	0.0301	0.9829	0.0358	1.0403	0.0336	1.0229
Mn	0.0239	4.1870	0.000324	0.0111	0.000311	0.0102	0.000351	0.0102	0.00037	0.0113
Mo	0.000156	0.0273	0.000011	0.0004	0.00001	0.0003	0.000015	0.0004	0.000013	0.0004
Ne	0.000123	0.0215	0.00007	0.0024	0.000054	0.0018	0.000058	0.0017	0.000068	0.0021
Nickel	0.0021	0.3679	0.000085	0.0029	0.000058	0.0019	0.00009	0.0026	0.000087	0.0026
Pr	0.00002	0.0035	0.00002	0.0007	0.00002	0.0007	0.00002	0.0006	0.00002	0.0006
Ruthenium	0.000062	0.0109	0.00002	0.0007	0.00002	0.0007	0.00002	0.0006	0.00002	0.0006
Samarium	0.000037	0.0065	0.000299	0.0102	0.000318	0.0104	0.000291	0.0085	0.000311	0.0095
*Strontium	0.00216	0.3784	0.00489	0.1671	0.00516	0.1685	0.00592	0.1720	0.00562	0.1711
Terbium	0.00002	0.0035	0.00002	0.0007	0.00002	0.0007	0.00002	0.0006	0.00002	0.0006
Titanium	0.000963	0.1687	0.000537	0.0184	0.000714	0.0233	0.000908	0.0264	0.000946	0.0288
*Zirconium	0.000994	0.1741	0.00148	0.0506	0.00162	0.0529	0.00245	0.0712	0.00255	0.0776
Antimony	0.000643	0.1126	0.0004	0.0137	0.0004	0.0131	0.000404	0.0117	0.000418	0.0127
Tin	0.0004	0.0701	0.0004	0.0137	0.0004	0.0131	0.0004	0.0116	0.0004	0.0122
Uranium	0.000839	0.1470	0.000491	0.0168	0.000553	0.0181	0.000692	0.0201	0.00228	0.0694
Others	0.4289	75.1419	0.0408	1.3959	0.0424	1.3847	0.0509	1.4780	0.0490	1.4923
Sum, mg	0.5708	100.0000	2.9260	100.0000	3.0623	100.0000	3.4414	100.0000	3.2847	100.0000
mg, Filter Loading										

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)
NOTE: Species in grey cells are minor impurity contents
Others: Sb, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Sm, Tb, Ti

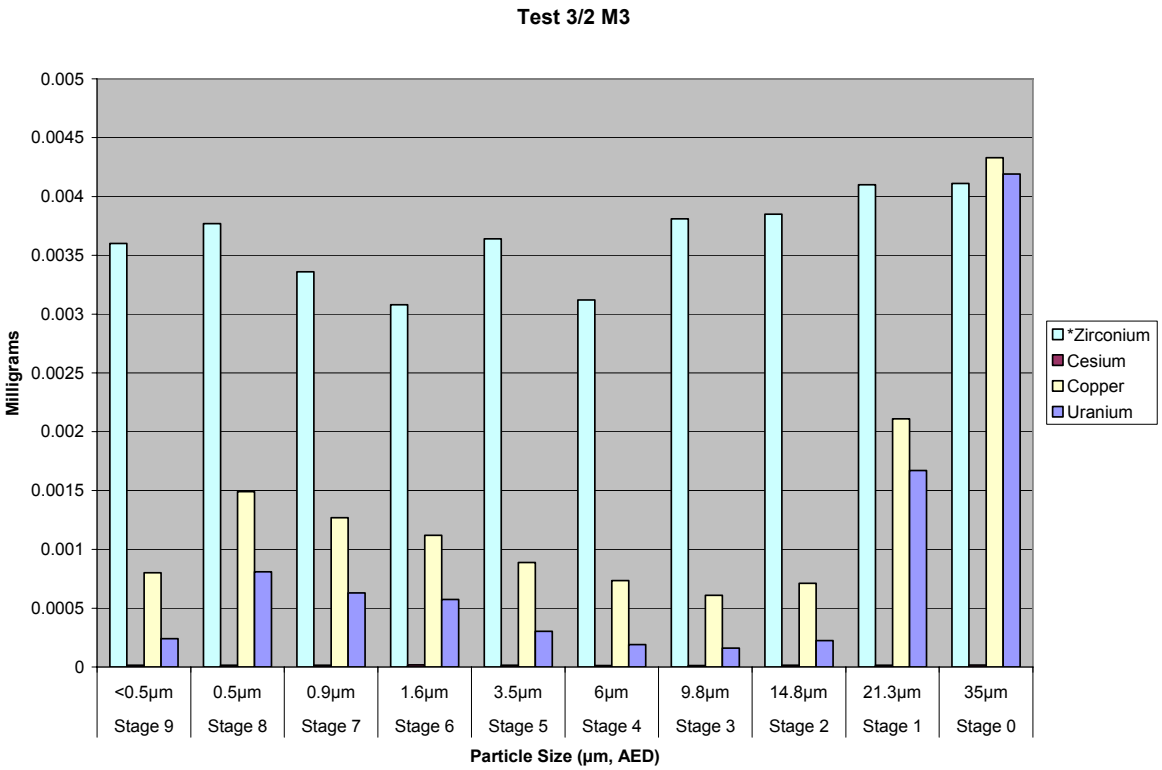


Figure A3.2A.11 Test 3/2 (A) Marple M3 Metals Analysis Distribution, mg

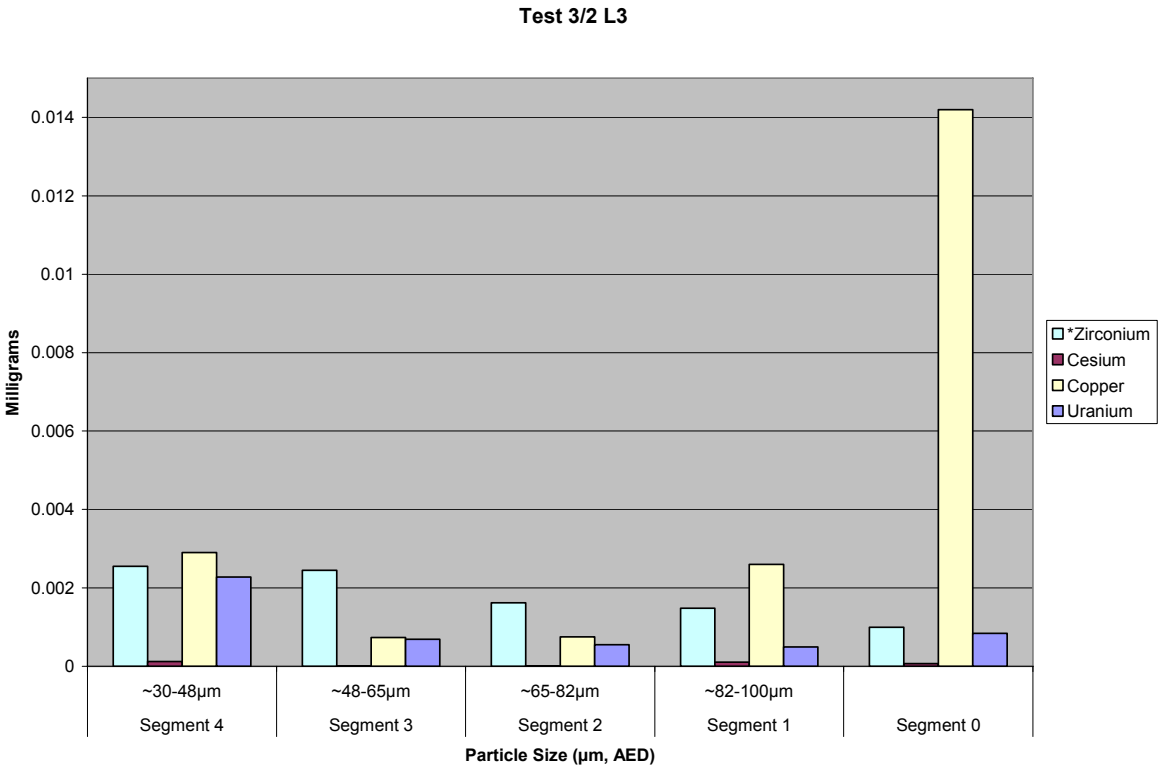


Figure A3.2A.12 Test 3/2 (A) LPS L3 Metals Analysis Distribution, mg

Table A3.2A.15 Test 3/2 (A) Marple M4 Elemental Analyses, Stages 0-3

3/2 (A)	STAGE 0			STAGE 1			STAGE 2			STAGE 3		
M4	Particle size 35 µm			Particle size 21.3 µm			Particle size 14.8 µm			Particle size 9.8 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	1.48	20.4910		1.45	22.4911		1.43	20.9432		1.3	22.4284	
*Barium	2.94	40.7051		2.62	40.6391		2.91	42.6187		2.39	41.2338	
*Boron	2.36	32.6749		2.07	32.1080		2.26	33.0991		1.91	32.9525	
Cerium	0.00126	0.0174	0.0486	0.000709	0.0110	0.1390	0.000738	0.0108		0.00116	0.0200	0.6824
Cesium	0.000021	0.0003	0.0008	0.000015	0.0002	0.0029	0.000015	0.0002		0.000012	0.0002	0.0071
Chromium	0.00179	0.0248	0.0691	0.00132	0.0205	0.2588	0.00106	0.0155		0.000909	0.0157	0.5347
Copper	0.0618	0.8556	2.3861	0.0377	0.5848	7.3922	0.018	0.2636		0.00879	0.1517	5.1706
Europium	0.000411	0.0057	0.0159	0.000339	0.0053	0.0665	0.000443	0.0065		0.000367	0.0063	0.2159
Iron	0.0898	1.2433	3.4672	0.0618	0.9586	12.1176	0.0418	0.6122		0.0381	0.6573	22.4118
La	0.000093	0.0013	0.0036	0.00009	0.0014	0.0176	0.000102	0.0015		0.000091	0.0016	0.0535
Lead	0.00117	0.0162	0.0452	0.000893	0.0139	0.1751	0.000773	0.0113		0.000594	0.0102	0.3494
Lithium	0.000394	0.0055	0.0152	0.000361	0.0056	0.0708	0.000413	0.0060		0.000347	0.0060	0.2041
*Mg	0.0732	1.0135		0.0742	1.1509		0.0815	1.1936		0.0647	1.1162	
Mn	0.00204	0.0282	0.0788	0.0015	0.0233	0.2941	0.0012	0.0176		0.00097	0.0167	0.5706
Mo	0.000124	0.0017	0.0048	0.000074	0.0011	0.0145	0.000041	0.0006		0.000024	0.0004	0.0141
Ne	0.000118	0.0016	0.0046	0.000108	0.0017	0.0212	0.000115	0.0017		0.000112	0.0019	0.0659
Nickel	0.00079	0.0109	0.0305	0.000515	0.0080	0.1010	0.000334	0.0049		0.000236	0.0041	0.1388
Pr	0.000024	0.0003	0.0009	0.000024	0.0004	0.0047	0.000026	0.0004		0.000024	0.0004	0.0141
Ruthenium	0.00002	0.0003	0.0008	0.00002	0.0003	0.0039	0.00002	0.0003		0.00002	0.0003	0.0118
Samarium	0.000628	0.0087	0.0242	0.000524	0.0081	0.1027	0.000671	0.0098		0.000568	0.0098	0.3341
*Strontium	0.0102	0.1412		0.00943	0.1463		0.0105	0.1538		0.00864	0.1491	
Terbium	0.00002	0.0003	0.0008	0.00002	0.0003	0.0039	0.00002	0.0003		0.00002	0.0003	0.0118
Titanium	0.00164	0.0227	0.0633	0.00112	0.0174	0.2196	0.00122	0.0179		0.000865	0.0149	0.5088
*Zirconium	0.0145	0.2008		0.00959	0.1488		0.00773	0.1132		0.00651	0.1123	
Antimony	0.000507	0.0070	0.0196	0.0004	0.0062	0.0784	0.000543	0.0080		0.000457	0.0079	0.2688
Tin	0.00213	0.0295	0.0822	0.00124	0.0192	0.2431	0.000419	0.0061		0.0004	0.0069	0.2353
Uranium	0.18	2.4921	6.9498	0.105	1.6287	20.5882	0.0603	0.8831		0.0623	1.0748	36.6471
Others	0.1724	2.3863	6.6546	0.1429	2.2170	28.0249	0.1298	1.9017		0.1080	1.8639	63.5512
Sum, mg	7.2227	100.0000	13.3120	6.4470	100.0000	41.9161	6.8280	100.0000	0.0000	5.7962	100.0000	68.4506
mg, Filter Loading	2.5900			0.5100			-0.0900			0.1700		

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)

NOTE: Species in grey cells are minor impurity contents

Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A3.2A.16 Test 3/2 (A) Marple M4 Elemental Analyses, Stages 4-7

3/2 (A)	STAGE 4			STAGE 5			STAGE 6			STAGE 7		
M4	Particle size 6.0 µm			Particle size 3.5 µm			Particle size 1.55 µm			Particle size 0.93 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	1.35	21.6145		1.71	24.5829		1.55	25.0854		1.49	22.7762	
*Barium	2.58	41.3078		2.52	36.2275		2.39	38.6800		2.71	41.4251	
*Boron	2.09	33.4625		2.05	29.4708		1.88	30.4261		2.07	31.6420	
Cerium	0.00141	0.0226	0.5222	0.00183	0.0263	0.1137	0.000463	0.0075	0.0572	0.000327	0.0050	0.0681
Cesium	0.000014	0.0002	0.0052	0.000015	0.0002	0.0009	0.000018	0.0003	0.0022	0.000015	0.0002	0.0031
Chromium	0.000998	0.0160	0.3696	0.0026	0.0374	0.1615	0.0017	0.0275	0.2099	0.00124	0.0190	0.2583
Copper	0.012	0.1921	4.4444	0.11	1.5814	6.8323	0.0523	0.8464	6.4568	0.0371	0.5671	7.7292
Europium	0.000395	0.0063	0.1463	0.000397	0.0057	0.0247	0.000376	0.0061	0.0464	0.000405	0.0062	0.0844
Iron	0.0405	0.6484	15.0000	0.142	2.0414	8.8199	0.0767	1.2413	9.4691	0.0539	0.8239	11.2292
La	0.000097	0.0016	0.0359	0.000097	0.0014	0.0060	0.000098	0.0016	0.0121	0.0001	0.0015	0.0208
Lead	0.000668	0.0107	0.2474	0.00153	0.0220	0.0950	0.000939	0.0152	0.1159	0.0009	0.0138	0.1875
Lithium	0.000364	0.0058	0.1348	0.000366	0.0053	0.0227	0.000346	0.0056	0.0427	0.000366	0.0056	0.0763
*Mg	0.0713	1.1416		0.0782	1.1242		0.0685	1.1086		0.0718	1.0975	
Mn	0.00109	0.0175	0.4037	0.00285	0.0410	0.1770	0.00167	0.0270	0.2062	0.00135	0.0206	0.2813
Mo	0.00003	0.0005	0.0111	0.0002	0.0029	0.0124	0.000108	0.0017	0.0133	0.000071	0.0011	0.0148
Ne	0.000119	0.0019	0.0441	0.000137	0.0020	0.0085	0.00011	0.0018	0.0136	0.000108	0.0017	0.0225
Nickel	0.000295	0.0047	0.1093	0.00127	0.0183	0.0789	0.000684	0.0111	0.0844	0.000467	0.0071	0.0973
Pr	0.000025	0.0004	0.0093	0.000025	0.0004	0.0016	0.000026	0.0004	0.0032	0.000026	0.0004	0.0054
Ruthenium	0.00002	0.0003	0.0074	0.00002	0.0003	0.0012	0.00002	0.0003	0.0025	0.00002	0.0003	0.0042
Samarium	0.000617	0.0099	0.2285	0.000618	0.0089	0.0384	0.00058	0.0094	0.0716	0.000625	0.0096	0.1302
*Strontium	0.00921	0.1475		0.00939	0.1350		0.00876	0.1418		0.00945	0.1445	
Terbium	0.00002	0.0003	0.0074	0.00002	0.0003	0.0012	0.00002	0.0003	0.0025	0.00002	0.0003	0.0042
Titanium	0.00107	0.0171	0.3963	0.00121	0.0174	0.0752	0.000825	0.0134	0.1019	0.00105	0.0161	0.2188
*Zirconium	0.00835	0.1337		0.021	0.3019		0.0103	0.1667		0.00859	0.1313	
Antimony	0.000706	0.0113	0.2615	0.00052	0.0075	0.0323	0.000404	0.0065	0.0499	0.00058	0.0089	0.1208
Tin	0.0004	0.0064	0.1481	0.00375	0.0539	0.2329	0.00195	0.0316	0.2407	0.00112	0.0171	0.2333
Uranium	0.0761	1.2184	28.1852	0.298	4.2840	18.5093	0.132	2.1363	16.2963	0.0823	1.2580	17.1458
Others	0.1179	1.8881	43.6778	0.2317	3.3305	14.3897	0.1527	2.4720	18.8568	0.1326	2.0276	27.6338
Sum, mg	6.2458	100.0000	50.7178	6.9560	100.0000	35.2457	6.1789	100.0000	33.4984	6.5419	100.0000	37.9354
mg, Filter Loading	0.2700			1.6100			0.8100			0.4800		

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)
NOTE: Species in grey cells are minor impurity contents
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A3.2A.17 Test 3/2 (A) Marple M4 Elemental Analyses, Stages 8-9

3/2 (A)	STAGE 8			STAGE 9		
M4	Particle size 0.52 µm			Particle size final, <0.5 µm		
	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	1.57	24.2895		1.55	22.0181	
*Barium	2.64	40.8435		2.98	42.3316	
*Boron	2.06	31.8703		2.36	33.5243	
Cerium	0.000283	0.0044	0.1665	0.00028	0.0040	
Cesium	0.000015	0.0002	0.0088	0.000018	0.0003	
Chromium	0.00101	0.0156	0.5941	0.000785	0.0112	
Copper	0.0181	0.2800	10.6471	0.0045	0.0639	
Europium	0.000432	0.0067	0.2541	0.000489	0.0069	
Iron	0.0347	0.5368	20.4118	0.0263	0.3736	
La	0.000111	0.0017	0.0653	0.00013	0.0018	
Lead	0.000718	0.0111	0.4224	0.000793	0.0113	
Lithium	0.00037	0.0057	0.2176	0.000424	0.0060	
*Mg	0.0794	1.2284		0.0894	1.2699	
Mn	0.00103	0.0159	0.6059	0.00096	0.0136	
Mo	0.000037	0.0006	0.0218	0.000016	0.0002	
Ne	0.000119	0.0018	0.0700	0.000142	0.0020	
Nickel	0.000222	0.0034	0.1306	0.000118	0.0017	
Pr	0.000029	0.0004	0.0171	0.000034	0.0005	
Ruthenium	0.00002	0.0003	0.0118	0.00002	0.0003	
Samarium	0.000673	0.0104	0.3959	0.000765	0.0109	
*Strontium	0.00943	0.1459		0.0104	0.1477	
Terbium	0.00002	0.0003	0.0118	0.00002	0.0003	
Titanium	0.000943	0.0146	0.5547	0.00104	0.0148	
*Zirconium	0.00669	0.1035		0.0058	0.0824	
Antimony	0.000745	0.0115	0.4382	0.000508	0.0072	
Tin	0.000503	0.0078	0.2959	0.0004	0.0057	
Uranium	0.0381	0.5894	22.4118	0.00632	0.0898	
Others	0.1202	1.8594	70.6994	0.1215	1.7259	
Sum, mg	6.4637	100.0000	57.7529	7.0397	100.0000	0.0000
mg, Filter Loading	0.1700			-0.0400		

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)

NOTE: Species in grey cells are minor impurity contents

Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A3.2A.18 Test 3/2 (A) LPS L4 Elemental Analyses

	Segment 0		Segment 1		Segment 2		Segment 3		Segment 4	
3/2 (A)	post swipe		~82-100 µm		~65-82 µm		~48-65 µm		~30-48 µm	
L4	mg	% detect	mg	% detect	mg	% detect	mg	% detect	mg	% detect
*Aluminum	0.017	3.4958	0.802	24.2401	0.509	25.2407	0.715	23.9286	0.955	25.5043
*Barium	0.0418	8.5957	1.42	42.9190	0.88	43.6382	1.29	43.1719	1.58	42.1956
*Boron	0.0033	0.6786	1.02	30.8291	0.589	29.2078	0.922	30.8562	1.04	27.7743
Cerium	0.00359	0.7382	0.000594	0.0180	0.000144	0.0071	0.000274	0.0092	0.00187	0.0499
Cesium	0.000288	0.0592	0.000054	0.0016	0.00001	0.0005	0.00001	0.0003	0.000034	0.0009
Chromium	0.00465	0.9562	0.000629	0.0190	0.000381	0.0189	0.000528	0.0177	0.000735	0.0196
Copper	0.0246	5.0587	0.00166	0.0502	0.000697	0.0346	0.00139	0.0465	0.00507	0.1354
Europium	0.000038	0.0078	0.000227	0.0069	0.000139	0.0069	0.000205	0.0069	0.000244	0.0065
Iron	0.303	62.3082	0.014	0.4231	0.00706	0.3501	0.0123	0.4116	0.0291	0.7771
La	0.000259	0.0533	0.000055	0.0017	0.000034	0.0017	0.000049	0.0016	0.000057	0.0015
Lead	0.000392	0.0806	0.000366	0.0111	0.000229	0.0114	0.000349	0.0117	0.000436	0.0116
Lithium	0.000252	0.0518	0.0002	0.0060	0.0002	0.0099	0.0002	0.0067	0.0002	0.0053
*Mg	0.0265	5.4494	0.035	1.0579	0.0215	1.0662	0.0303	1.0140	0.0392	1.0469
Mn	0.0167	3.4342	0.000372	0.0112	0.000211	0.0105	0.000338	0.0113	0.000612	0.0163
Mo	0.000151	0.0311	0.000011	0.0003	0.00001	0.0005	0.00001	0.0003	0.000019	0.0005
Ne	0.000201	0.0413	0.000064	0.0019	0.00004	0.0020	0.000057	0.0019	0.000093	0.0025
Nickel	0.00387	0.7958	0.00014	0.0042	0.00005	0.0025	0.000108	0.0036	0.000253	0.0068
Pr	0.00004	0.0082	0.00002	0.0006	0.00002	0.0010	0.00002	0.0007	0.00002	0.0005
Ruthenium	0.000051	0.0105	0.00002	0.0006	0.00002	0.0010	0.00002	0.0007	0.00002	0.0005
Samarium	0.00004	0.0082	0.000343	0.0104	0.000214	0.0106	0.000318	0.0106	0.000374	0.0100
*Strontium	0.00169	0.3475	0.00571	0.1726	0.00347	0.1721	0.00528	0.1767	0.0063	0.1682
Terbium	0.00002	0.0041	0.00002	0.0006	0.00002	0.0010	0.00002	0.0007	0.00002	0.0005
Titanium	0.00063	0.1296	0.000556	0.0168	0.000395	0.0196	0.00035	0.0117	0.000668	0.0178
*Zirconium	0.00283	0.5820	0.00193	0.0583	0.00118	0.0585	0.00158	0.0529	0.00533	0.1423
Antimony	0.0004	0.0823	0.0004	0.0121	0.0004	0.0198	0.0004	0.0134	0.000508	0.0136
Tin	0.0004	0.0823	0.0004	0.0121	0.0004	0.0198	0.0004	0.0134	0.0004	0.0107
Uranium	0.0336	6.9094	0.00379	0.1146	0.00176	0.0873	0.00655	0.2192	0.0779	2.0804
Others	0.3569	73.3903	0.0522	1.5778	0.0307	1.5225	0.0454	1.5178	0.0723	1.9319
Sum, mg	0.4863	100.0000	3.3086	100.0000	2.0166	100.0000	2.9881	100.0000	3.7445	100.0000
mg, Filter Loading										

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)
NOTE: Species in grey cells are minor impurity contents
Others: Sb, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Sm, Tb, Ti

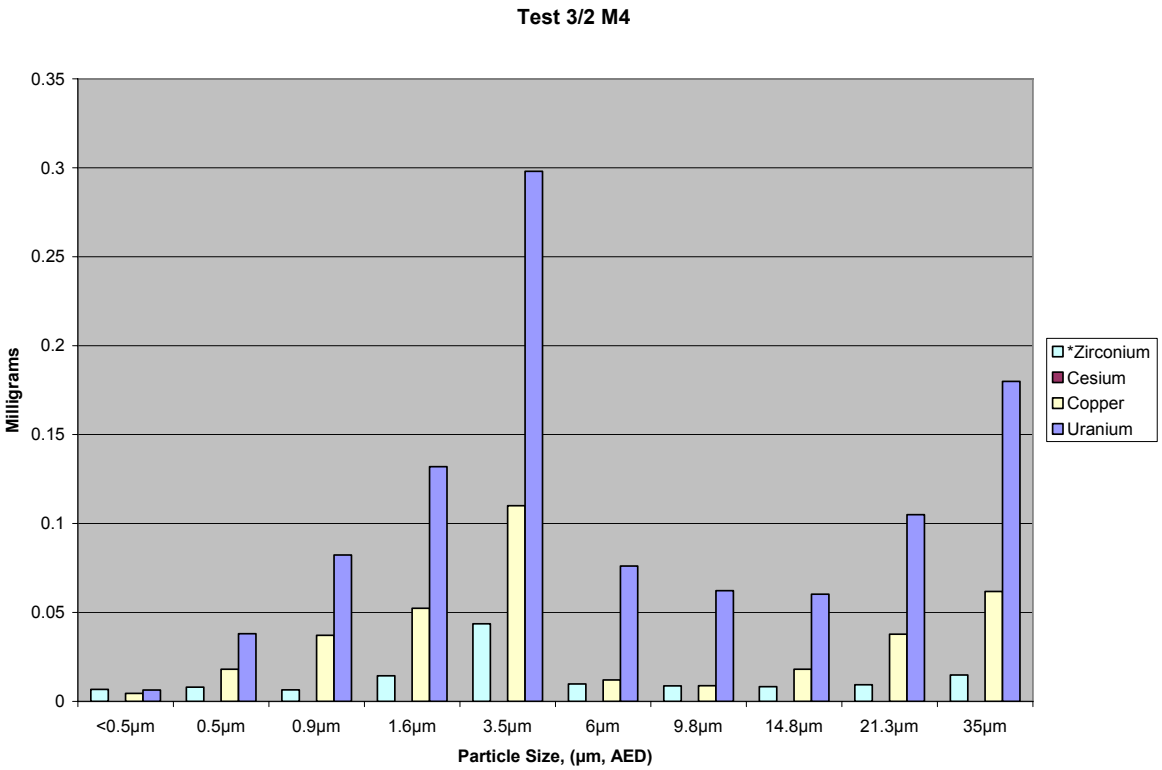


Figure A3.2A.13 Test 3/2 (A) Marple M4 Metals Analysis Distribution, mg

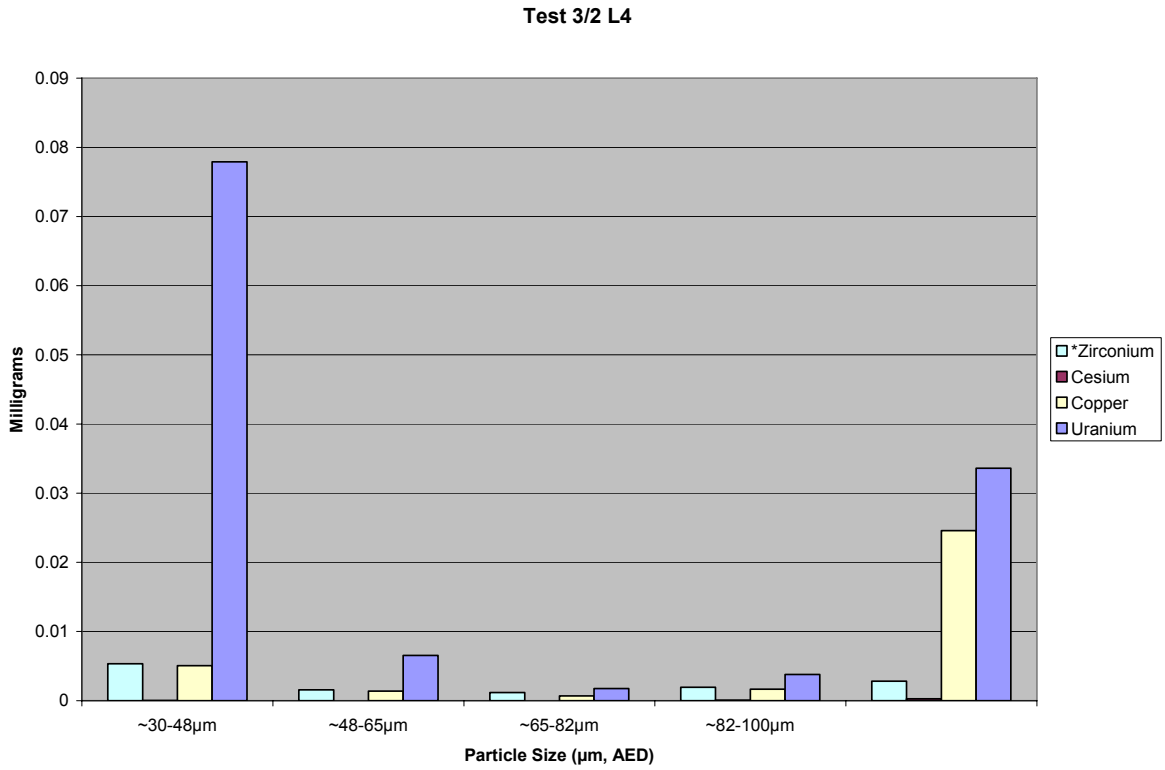


Figure A3.2A.14 Test 3/2 (A) LPS L4 Metals Analysis Distribution, mg

A.3.5B Test 3/5 (B) Analyses and Results

Particulates from the Phase 3 DUO_2 test 3/5 (B) were sampled using four independent Marple impactor and Large Particle Separator systems. In addition, multiple separate impact particle debris samples were collected by a HEPA vacuum system and a pre-separator paper liner (collection bag). The impact particle debris was subsequently mechanically sieved and chemically analyzed by ICP-MS. Surface deposited particle samples were also obtained from the exterior and interior of each of the four internal chamber sampling tubes. All sample materials collected contain depleted uranium and were, therefore, slightly radioactive. These samples required special, appropriate handling.

Gravimetric and Debris Analyses: Graphs of gravimetric particle size distributions from the four 3/5 (B) Marple impactors, plus the mass concentrations, are presented in Figures A3.5B.15 to Figure A3.5B.19. The weight distribution of the sieved particle impact debris is presented in Table A3.5B.19. Table A3.5B.20 contains the measured impact debris elemental analysis, in mg/kg, for the particles from 90 to 38 µm (geometric) size, or 290 to 123 µm AED for DUO_2 particles. The weight percent distribution of metals on the impact debris sieved fractions is plotted in Figure A3.5B.20. The fission product species Cs, Ru, Sr, and Eu are not plotted; they were not added as dopants and are present only as minimal impurities.

Table A3.5B.19 Test 3/5 (B), Weight Distribution of Impact Debris

Particle Density		Particle Density 95%				
1.00 g/cc		10.41 g/cc				
Sieve #	Opening Size (geom.)	AED Size for DUO_2	Weight, g Retained	Weight, g Passed	Percent Passed	Percent Retained
25	710 µm	2290 µm	57.910	26.22	31.165%	68.835%
35	500 µm	1610 µm	3.762	22.46	26.694%	4.472%
60	250 µm	807 µm	10.085	12.37	14.706%	11.988%
120	125 µm	403 µm	9.618	2.75	3.274%	11.432%
170	90 µm	290 µm	1.848	0.91	1.077%	2.197%
200	75 µm	242 µm	0.061	0.85	1.004%	0.073%
400	38 µm	123 µm	0.819	0.03	0.031%	0.974%
600	25 µm	81 µm	0.026	0.00	0.000%	0.031%
pan	< 25 µm	< 81 µm	0.000	0.00	0.000%	0.000%
totals			84.129			100.00%

Marple and LPS Particle Element Analyses: Chemical analyses were performed on all four of the Marple and LPS particle collection systems. Each Large Particle Sampler fiberglass substrate was cut into four separate pieces prior to chemical dissolution and elemental analysis by ICP-MS. These LPS segments cover the nominal particle size range of: Segment #1 is ~82-100 µm AED, Segment #2 is ~65-82 µm AED, Segment #3 is ~48-65 µm AED, and Segment #4 is ~30-48 µm AED.

All Marple M1 elemental analyses are listed in Tables A3.5B.21 to A3.5B.23 and are plotted in Figure A3.5B.21 for metals. All LPS L1 elemental analyses are listed in Table A3.5B.24 and are plotted in Figure A3.5B.22 for metals.

All Marple M2 elemental analyses are listed in Tables A3.5B.25 to A3.5B.27 and are plotted in Figure A3.5B.23. All LPS L2 elemental analyses are listed in Table A3.5B.28 and are plotted in Figure A3.5B.24.

All Marple M3 elemental analyses are listed in Tables A3.5B.29 to A3.5B.31 and are plotted in Figure A3.5B.25. All LPS L3 elemental analyses are listed in Table A3.5B.32 and are plotted in Figure A3.5B.26.

All Marple M4 elemental analyses are listed in Tables A3.5B.33 to A3.5B.35 and are plotted in Figure A3.5B.27. All LPS L4 elemental analyses are listed in Table A3.5B.36 and are plotted in Figure A3.5B.28.

Table A3.5B.20 Test 3/5 (B) Impact Debris Metals Distribution, mg/kg

3/5 D10 mg/kg	D10-25	D10-38	D10-75	D10-90	
Sieve Opening	25	38 µm	75 µm	90 µm	
*Aluminum	16200	6490	43200	25300	
*Barium	2.77	0.492	3.12	2.4	
*Boron	60.9	4.87	9.24	6.11	
Cerium	847	120	915	654	
Cesium	3.11	0.798	3.98	2.64	
Chromium	359	81.4	557	296	
Copper	11400	1210	11500	8010	
Europium	0.769	0.0405	0.19	0.1	
Iron	53900	10800	93200	65600	
Lanthanum	0.769	0.0679	0.361	0.262	
Lead	73.5	16	89.8	62.9	
Lithium	7.69	0.253	1.07	0.718	
*Magnesium	320	71.1	536	280	
Manganese	594	127	1020	621	
Molybdenum	24	5.36	35.5	24.8	
Neodymium	19.2	1.95	21.9	13	
Nickel	361	72	527	386	
Praseodymium	0.769	0.0244	0.0842	0.0637	
Ruthenium	0.769	0.0713	0.338	0.211	
Samarium	0.769	0.0244	0.0824	0.059	
*Strontium	7.69	0.26	1.45	1.07	
Terbium	0.769	0.0244	0.126	0.0899	
Titanium	137	31.3	239	188	
*Zirconium	3920	324	3260	1810	
Antimony	133	17.3	120	65.2	
Tin	15.4	1.22	7.91	7.89	
Uranium	133000	15500	132000	117000	
Others	11223.5916	96347.0436	67537.4746	0.0000	
mg, Metals Found	221,389.87	34,875.56	287,249.15	220,332.51	

Others: Sb, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Sm, Tb, Ti
*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)

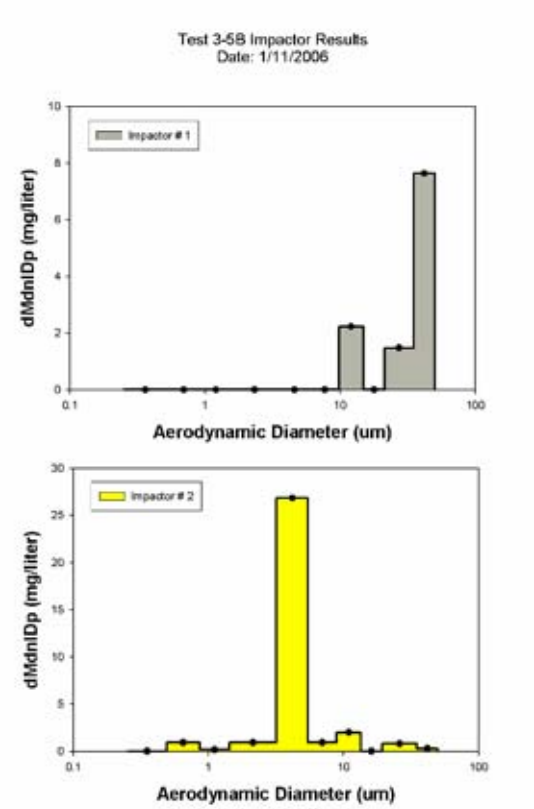


Figure A3.5B.15 Test 3/2 (A) Marple #1 Size Distribution

Figure A3.5B.16 Test 3/2 (A) Marple #2 Size Distribution

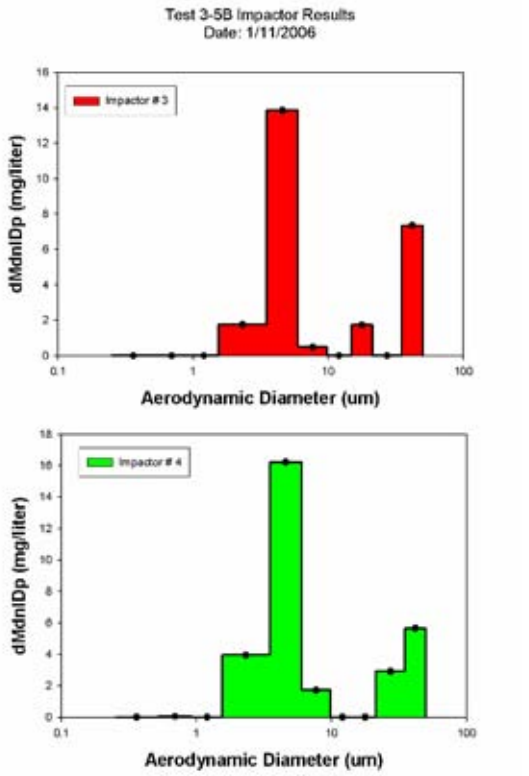


Figure A3.5B.17 Test 3/2 (A) Marple #3 Size Distribution

Figure A3.5B.18 Test 3/2 (A) Marple #4 Size Distribution

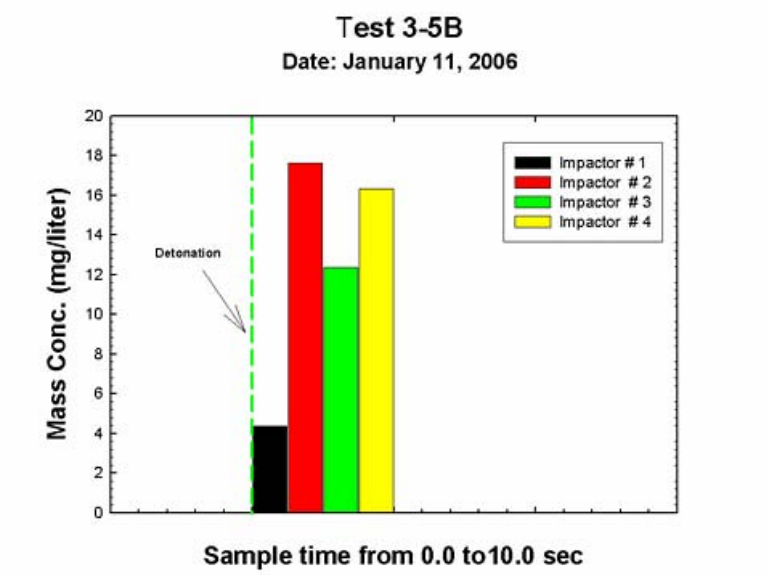


Figure A3.5B.19 Test 3/5 (B) Marple Impactor Mass Concentration Data

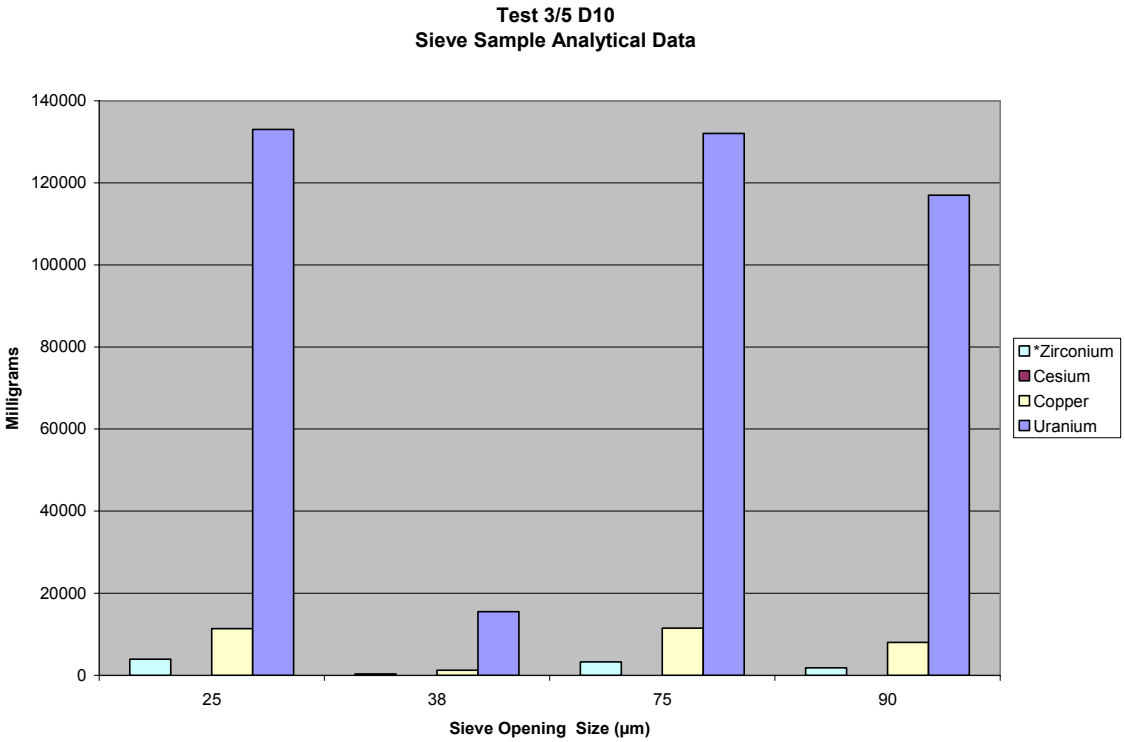


Figure A3.5B.20 Test 3/5 (B) Metals Weight Percent Distribution, Impact Debris Fractions

Table A3.5B.21 Test 3/5 (B) Marple M1 Elemental Analyses, Stages 0-3

3/5 (B)	STAGE 0			STAGE 1			STAGE 2			STAGE 3		
M1	Particle size 35 µm			Particle size 21.3 µm			Particle size 14.8 µm			Particle size 9.8 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	0.0421	14.4152		0.0221	14.5273		0.0136	15.2916		0.0109	14.7485	
*Barium	0.000851	0.2914		0.00089	0.5850		0.000893	1.0041		0.00124	1.6778	
*Boron	0.000787	0.2695		0.00077	0.5062		0.000741	0.8332		0.00123	1.6643	
Cerium	0.000397	0.1359	0.0254	0.000242	0.1591	0.0484	0.000162	0.1821	0.0386	0.00033	0.4465	0.2200
Cesium	0.00001	0.0034	0.0006	0.00001	0.0066	0.0020	0.00001	0.0112	0.0024	0.00001	0.0135	0.0067
Chromium	0.00123	0.4212	0.0788	0.000918	0.6034	0.1836	0.000303	0.3407	0.0721	0.000336	0.4546	0.2240
Copper	0.0294	10.0667	1.8846	0.0157	10.3203	3.1400	0.00846	9.5122	2.0143	0.00706	9.5527	4.7067
Europium	0.00002	0.0068	0.0013	0.00002	0.0131	0.0040	0.00002	0.0225	0.0048	0.00002	0.0271	0.0133
Iron	0.0481	16.4696	3.0833	0.0271	17.8141	5.4200	0.0149	16.7532	3.5476	0.0158	21.3785	10.5333
La	0.00002	0.0068	0.0013	0.00002	0.0131	0.0040	0.00002	0.0225	0.0048	0.00002	0.0271	0.0133
Lead	0.000488	0.1671	0.0313	0.000255	0.1676	0.0510	0.000152	0.1709	0.0362	0.000135	0.1827	0.0900
Lithium	0.0002	0.0685	0.0128	0.0002	0.1315	0.0400	0.0002	0.2249	0.0476	0.0002	0.2706	0.1333
*Mg	0.00283	0.9690		0.00202	1.3278		0.00249	2.7997		0.00275	3.7209	
Mn	0.000832	0.2849	0.0533	0.000431	0.2833	0.0862	0.000234	0.2631	0.0557	0.000249	0.3369	0.1660
Mo	0.000126	0.0431	0.0081	0.000102	0.0670	0.0204	0.000037	0.0416	0.0088	0.000035	0.0474	0.0233
Ne	0.00002	0.0068	0.0013	0.00002	0.0131	0.0040	0.00002	0.0225	0.0048	0.00002	0.0271	0.0133
Nickel	0.000862	0.2952	0.0553	0.000583	0.3832	0.1166	0.000245	0.2755	0.0583	0.000251	0.3396	0.1673
Pr	0.00002	0.0068	0.0013	0.00002	0.0131	0.0040	0.00002	0.0225	0.0048	0.00002	0.0271	0.0133
Ruthenium	0.00002	0.0068	0.0013	0.00002	0.0131	0.0040	0.00002	0.0225	0.0048	0.00002	0.0271	0.0133
Samarium	0.00002	0.0068	0.0013	0.00002	0.0131	0.0040	0.00002	0.0225	0.0048	0.00002	0.0271	0.0133
*Strontium	0.0002	0.0685		0.0002	0.1315		0.0002	0.2249		0.0002	0.2706	
Terbium	0.00002	0.0068	0.0013	0.00002	0.0131	0.0040	0.00002	0.0225	0.0048	0.00002	0.0271	0.0133
Titanium	0.0002	0.0685	0.0128	0.0002	0.1315	0.0400	0.0002	0.2249	0.0476	0.0002	0.2706	0.1333
*Zirconium	0.00885	3.0303		0.00431	2.8332		0.00256	2.8784		0.00334	4.5193	
Antimony	0.0004	0.1370	0.0256	0.00075	0.4930	0.1500	0.000811	0.9119	0.1931	0.0004	0.5412	0.2667
Tin	0.00105	0.3595	0.0673	0.000406	0.2669	0.0812	0.0004	0.4498	0.0952	0.0004	0.5412	0.2667
Uranium	0.153	52.3878	9.8077	0.0748	49.1694	14.9600	0.0422	47.4488	10.0476	0.0287	38.8331	19.1333
Others	0.0552	18.8966	3.5377	0.0325	21.3499	6.4958	0.0195	21.9164	4.6410	0.0203	27.4348	13.5173
Sum, mg	0.2921	47.1158	15.1561	0.1521	50.0707	24.3674	0.0889	51.1896	16.2986	0.0739	60.0844	36.1640
mg, Filter Loading												

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)

NOTE: Species in grey cells are minor impurity contents

Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A3.5B.22 Test 3/5 (B) Marple M1 Elemental Analyses, Stages 4-7

3/5 (B)	STAGE 4			STAGE 5			STAGE 6			STAGE 7		
M1	Particle size 6.0 µm			Particle size 3.5 µm			Particle size 1.55 µm			Particle size 0.93 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	0.0104	11.7583		0.102	18.6783		0.0297	16.2749		0.00431	21.1233	
*Barium	0.00101	1.1419		0.00105	0.1923		0.001	0.5480		0.000804	3.9404	
*Boron	0.000749	0.8468		0.000817	0.1496		0.000786	0.4307		0.000549	2.6906	
Cerium	0.000257	0.2906	0.1071	0.000264	0.0483	0.0518	0.000089	0.0488	0.0099	0.00002	0.0980	0.0105
Cesium	0.00001	0.0113	0.0042	0.00001	0.0018	0.0020	0.00001	0.0055	0.0011	0.00001	0.0490	0.0053
Chromium	0.000217	0.2453	0.0904	0.00187	0.3424	0.3667	0.000559	0.3063	0.0621	0.0001	0.4901	0.0526
Copper	0.00569	6.4332	2.3708	0.0667	12.2142	13.0784	0.0251	13.7542	2.7889	0.00172	8.4297	0.9053
Europium	0.00002	0.0226	0.0083	0.00002	0.0037	0.0039	0.00002	0.0110	0.0022	0.00002	0.0980	0.0105
Iron	0.0131	14.8110	5.4583	0.0942	17.2500	18.4706	0.0294	16.1105	3.2667	0.00276	13.5268	1.4526
La	0.00002	0.0226	0.0083	0.00002	0.0037	0.0039	0.00002	0.0110	0.0022	0.00002	0.0980	0.0105
Lead	0.000102	0.1153	0.0425	0.000998	0.1828	0.1957	0.000329	0.1803	0.0366	0.00005	0.2450	0.0263
Lithium	0.0002	0.2261	0.0833	0.0002	0.0366	0.0392	0.0002	0.1096	0.0222	0.0002	0.9802	0.1053
*Mg	0.0021	2.3743		0.00329	0.6025		0.00216	1.1836		0.00207	10.1451	
Mn	0.000201	0.2273	0.0838	0.00162	0.2967	0.3176	0.000494	0.2707	0.0549	0.0001	0.4901	0.0526
Mo	0.000025	0.0283	0.0104	0.000221	0.0405	0.0433	0.000077	0.0422	0.0086	0.00001	0.0490	0.0053
Ne	0.00002	0.0226	0.0083	0.00002	0.0037	0.0039	0.00002	0.0110	0.0022	0.00002	0.0980	0.0105
Nickel	0.000167	0.1888	0.0696	0.00144	0.2637	0.2824	0.000409	0.2241	0.0454	0.00005	0.2450	0.0263
Pr	0.00002	0.0226	0.0083	0.00002	0.0037	0.0039	0.00002	0.0110	0.0022	0.00002	0.0980	0.0105
Ruthenium	0.00002	0.0226	0.0083	0.00002	0.0037	0.0039	0.00002	0.0110	0.0022	0.00002	0.0980	0.0105
Samarium	0.00002	0.0226	0.0083	0.00002	0.0037	0.0039	0.00002	0.0110	0.0022	0.00002	0.0980	0.0105
*Strontium	0.0002	0.2261		0.0002	0.0366		0.0002	0.1096		0.0002	0.9802	
Terbium	0.00002	0.0226	0.0083	0.00002	0.0037	0.0039	0.00002	0.0110	0.0022	0.00002	0.0980	0.0105
Titanium	0.0002	0.2261	0.0833	0.000207	0.0379	0.0406	0.0002	0.1096	0.0222	0.0002	0.9802	0.1053
*Zirconium	0.00298	3.3692		0.0168	3.0764		0.00613	3.3591		0.000471	2.3084	
Antimony	0.0004	0.4522	0.1667	0.0004	0.0732	0.0784	0.000512	0.2806	0.0569	0.0004	1.9604	0.2105
Tin	0.0004	0.4522	0.1667	0.00166	0.3040	0.3255	0.000795	0.4356	0.0883	0.0004	1.9604	0.2105
Uranium	0.0499	56.4173	20.7917	0.252	46.1465	49.4118	0.0842	46.1395	9.3556	0.00584	28.6218	3.0737
Others	0.0166	18.8043	6.9300	0.1044	19.1116	20.4639	0.0343	18.7736	3.8067	0.0059	28.7199	3.0842
Sum, mg	0.0884	42.6782	29.5871	0.5461	53.4763	82.7314	0.1825	53.1443	15.8349	0.0204	67.4574	6.3158
mg, Filter Loading												

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)

NOTE: Species in grey cells are minor impurity contents

Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A3.5B.23 Test 3/5 (B) Marple M1 Elemental Analyses, Stages 8-9

3/5 (B)	STAGE 8			STAGE 9		
M1	Particle size 0.52 µm			Particle size final, <0.5 µm		
	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	0.0108	31.3125		0.00255	16.5531	
*Barium	0.000769	2.2296		0.000451	2.9276	
*Boron	0.000496	1.4381		0.0004	2.5966	
Cerium	0.00002	0.0580	0.0125	0.00002	0.1298	
Cesium	0.00001	0.0290	0.0063	0.00001	0.0649	
Chromium	0.0001	0.2899	0.0625	0.0001	0.6491	
Copper	0.00333	9.6547	2.0813	0.00148	9.6073	
Europium	0.00002	0.0580	0.0125	0.00002	0.1298	
Iron	0.00393	11.3943	2.4563	0.0023	14.9302	
La	0.00002	0.0580	0.0125	0.00002	0.1298	
Lead	0.000052	0.1508	0.0325	0.00005	0.3246	
Lithium	0.0002	0.5799	0.1250	0.0002	1.2983	
*Mg	0.00223	6.4655		0.00257	16.6829	
Mn	0.0001	0.2899	0.0625	0.0001	0.6491	
Mo	0.000015	0.0435	0.0094	0.00001	0.0649	
Ne	0.00002	0.0580	0.0125	0.00002	0.1298	
Nickel	0.000075	0.2174	0.0469	0.000054	0.3505	
Pr	0.00002	0.0580	0.0125	0.00002	0.1298	
Ruthenium	0.00002	0.0580	0.0125	0.00002	0.1298	
Samarium	0.00002	0.0580	0.0125	0.00002	0.1298	
*Strontium	0.0002	0.5799		0.0002	1.2983	
Terbium	0.00002	0.0580	0.0125	0.00002	0.1298	
Titanium	0.0002	0.5799	0.1250	0.0002	1.2983	
*Zirconium	0.000824	2.3890		0.00032	2.0772	
Antimony	0.0004	1.1597	0.2500	0.0004	2.5966	
Tin	0.0004	1.1597	0.2500	0.0004	2.5966	
Uranium	0.0102	29.5729	6.3750	0.00345	22.3953	
Others	0.0072	20.9388	4.5138	0.0059	38.3252	
Sum, mg	0.0345	68.1076	11.9825	0.0154	72.4116	0.0000
mg, Metals Found						

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)
NOTE: Species in grey cells are minor impurity contents
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A3.5B.24 Test 3/2 (A) LPS L1 Elemental Analyses

	Segment 4		Segment 3		Segment 2		Segment 1		Segment 0	
3/5 (B)	~30-48µm		~48-65µm		~65-82µm		~82-100µm		post-swipe	
L1	mg	% detect	mg	% detect	mg	% detect	mg	% detect	mg	% detect
*Aluminum	0.00363	0.00203	0.00281	0.00419	0.0971	0.00363	0.00203	0.00281	0.00419	0.0971
*Barium	0.000227	0.000198	0.000232	0.000319	0.00771	0.000227	0.000198	0.000232	0.000319	0.00771
*Boron	0.0004	0.0004	0.0004	0.0004	0.0189	0.0004	0.0004	0.0004	0.0004	0.0189
Cerium	0.00027	0.000102	0.000273	0.000962	0.00269	0.00027	0.000102	0.000273	0.000962	0.00269
Cesium	0.00001	0.00001	0.00001	0.00001	0.000031	0.00001	0.00001	0.00001	0.00001	0.000031
Chromium	0.000293	0.000146	0.00027	0.000551	0.00379	0.000293	0.000146	0.00027	0.000551	0.00379
Copper	0.00314	0.00259	0.00356	0.00496	0.00903	0.00314	0.00259	0.00356	0.00496	0.00903
Europium	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002
Iron	0.00647	0.00545	0.0104	0.0144	0.0425	0.00647	0.00545	0.0104	0.0144	0.0425
La	0.00002	0.00002	0.00002	0.00002	0.000025	0.00002	0.00002	0.00002	0.00002	0.000025
Lead	0.00005	0.00005	0.00005	0.000063	0.000211	0.00005	0.00005	0.00005	0.000063	0.000211
Lithium	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
*Mg	0.0005	0.000512	0.000816	0.000713	0.0624	0.0005	0.000512	0.000816	0.000713	0.0624
Mn	0.0001	0.0001	0.000108	0.000167	0.0206	0.0001	0.0001	0.000108	0.000167	0.0206
Mo	0.000018	0.000011	0.000017	0.000026	0.000144	0.000018	0.000011	0.000017	0.000026	0.000144
Ne	0.00002	0.00002	0.00002	0.00002	0.000038	0.00002	0.00002	0.00002	0.00002	0.000038
Nickel	0.000169	0.000098	0.000139	0.00029	0.00263	0.000169	0.000098	0.000139	0.00029	0.00263
Pr	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002
Ruthenium	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002
Samarium	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002
*Strontium	0.0002	0.0002	0.0002	0.0002	0.00269	0.0002	0.0002	0.0002	0.0002	0.00269
Terbium	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002
Titanium	0.0002	0.0002	0.0002	0.0002	0.000216	0.0002	0.0002	0.0002	0.0002	0.000216
*Zirconium	0.000988	0.000743	0.00167	0.00246	0.00211	0.000988	0.000743	0.00167	0.00246	0.00211
Antimony	0.0004	0.0004	0.000421	0.0004	0.0004	0.0004	0.0004	0.000421	0.0004	0.0004
Tin	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
Uranium	0.0117	0.0183	0.0418	0.0665	0.0381	0.0117	0.0183	0.0418	0.0665	0.0381
Others	0.0083	0.0071	0.0125	0.0169	0.1330	0.0083	0.0071	0.0125	0.0169	0.1330
Sum, mg	0.0295	0.0323	0.0641	0.0976	0.3120	0.0295	0.0323	0.0641	0.0976	0.3120
mg, Filter Loading	0.00363	0.00203	0.00281	0.00419	0.0971	0.00363	0.00203	0.00281	0.00419	0.0971

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)
NOTE: Species in grey cells are minor impurity contents
Others: Sb, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Sm, Tb, Ti

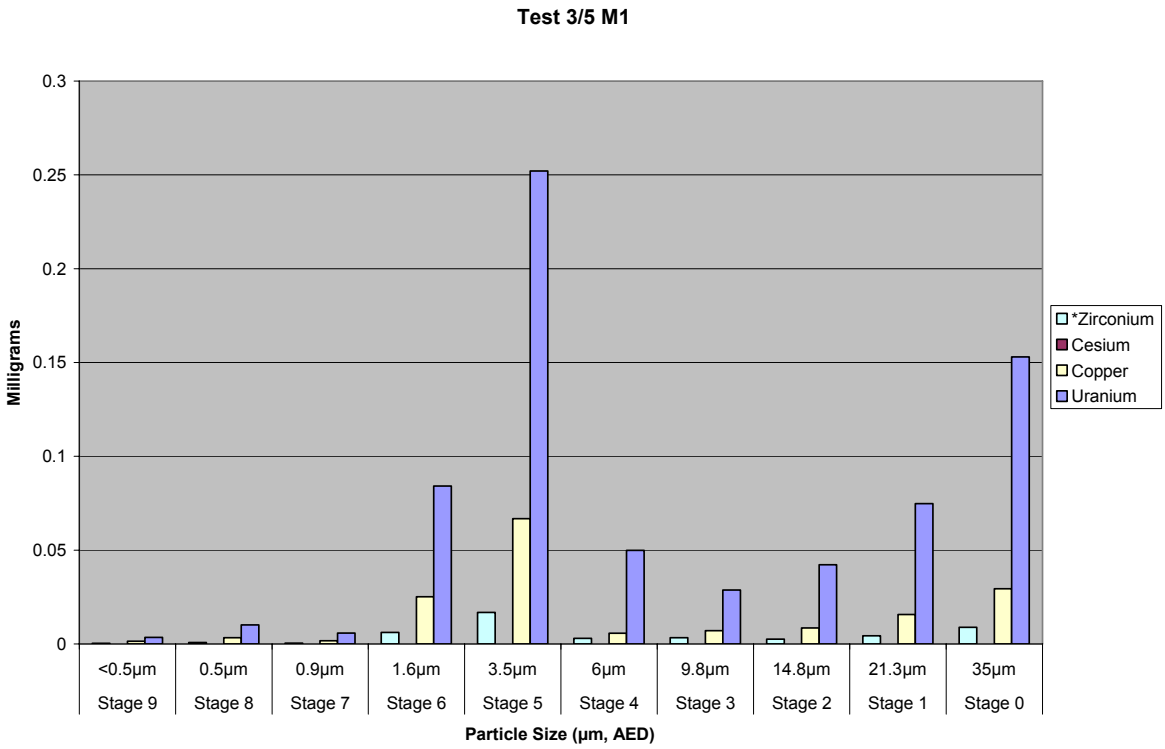


Figure A3.5B.21 Test 3/5 (B) Marple M1 Metals Analysis Distribution, mg

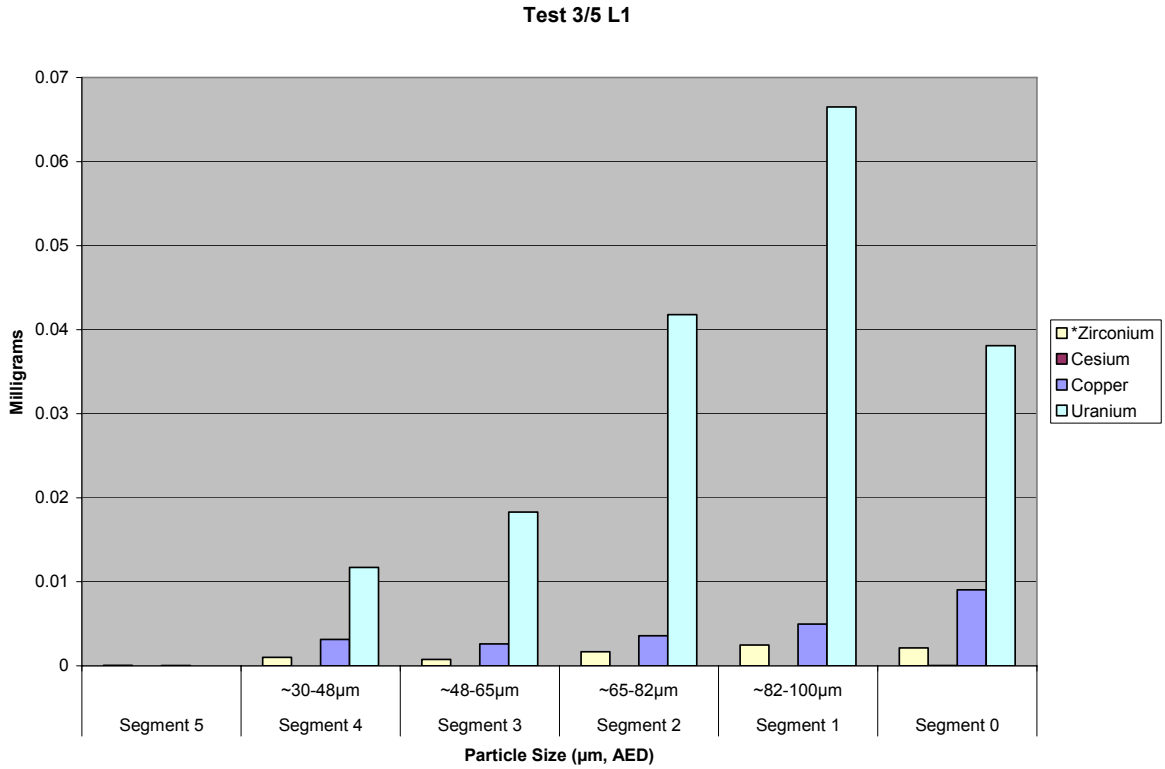


Figure A3.5B.22 Test 3/5 (B) LPS L1 Metals Analysis Distribution, mg

Table A3.5B.25 Test 3/5 (B) Marple M2 Elemental Analyses, Stages 0-3

3/5 (B)	STAGE 0			STAGE 1			STAGE 2			STAGE 3		
M2	Particle size 35 µm			Particle size 21.3 µm			Particle size 14.8 µm			Particle size 9.8 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	0.0569	16.4432		0.028	16.5477		0.0135	15.8956		0.0107	11.2406	
*Barium	0.000855	0.2471		0.000932	0.5508		0.00103	1.2128		0.00155	1.6283	
*Boron	0.000572	0.1653		0.000665	0.3930		0.000802	0.9443		0.00144	1.5127	
Cerium	0.000453	0.1309	0.0248	0.000236	0.1395	0.0944	0.000186	0.2190	0.0930	0.000316	0.3320	0.0626
Cesium	0.00001	0.0029	0.0005	0.00001	0.0059	0.0040	0.00001	0.0118	0.0050	0.00001	0.0105	0.0020
Chromium	0.00116	0.3352	0.0634	0.000526	0.3109	0.2104	0.000211	0.2484	0.1055	0.000198	0.2080	0.0392
Copper	0.0338	9.7677	1.8470	0.0163	9.6331	6.5200	0.00681	8.0185	3.4050	0.00499	5.2421	0.9881
Europium	0.00002	0.0058	0.0011	0.00002	0.0118	0.0080	0.00002	0.0235	0.0100	0.00002	0.0210	0.0040
Iron	0.0628	18.1482	3.4317	0.0302	17.8479	12.0800	0.0151	17.7796	7.5500	0.015	15.7578	2.9703
La	0.00002	0.0058	0.0011	0.00002	0.0118	0.0080	0.00002	0.0235	0.0100	0.00002	0.0210	0.0040
Lead	0.000651	0.1881	0.0356	0.000321	0.1897	0.1284	0.000138	0.1625	0.0690	0.000107	0.1124	0.0212
Lithium	0.0002	0.0578	0.0109	0.0002	0.1182	0.0800	0.0002	0.2355	0.1000	0.0002	0.2101	0.0396
*Mg	0.00297	0.8583		0.00403	2.3817		0.00223	2.6257		0.0027	2.8364	
Mn	0.00148	0.4277	0.0809	0.000499	0.2949	0.1996	0.000233	0.2743	0.1165	0.000214	0.2248	0.0424
Mo	0.000128	0.0370	0.0070	0.00007	0.0414	0.0280	0.00003	0.0353	0.0150	0.000027	0.0284	0.0053
Ne	0.00002	0.0058	0.0011	0.00002	0.0118	0.0080	0.00002	0.0235	0.0100	0.00002	0.0210	0.0040
Nickel	0.000899	0.2598	0.0491	0.000459	0.2713	0.1836	0.000209	0.2461	0.1045	0.000199	0.2091	0.0394
Pr	0.00002	0.0058	0.0011	0.00002	0.0118	0.0080	0.00002	0.0235	0.0100	0.00002	0.0210	0.0040
Ruthenium	0.00002	0.0058	0.0011	0.00002	0.0118	0.0080	0.00002	0.0235	0.0100	0.00002	0.0210	0.0040
Samarium	0.00002	0.0058	0.0011	0.00002	0.0118	0.0080	0.00002	0.0235	0.0100	0.00002	0.0210	0.0040
*Strontium	0.0002	0.0578		0.0002	0.1182		0.0002	0.2355		0.0002	0.2101	
Terbium	0.00002	0.0058	0.0011	0.00002	0.0118	0.0080	0.00002	0.0235	0.0100	0.00002	0.0210	0.0040
Titanium	0.0002	0.0578	0.0109	0.0002	0.1182	0.0800	0.0002	0.2355	0.1000	0.0002	0.2101	0.0396
*Zirconium	0.0103	2.9765		0.00492	2.9077		0.0025	2.9436		0.0031	3.2566	
Antimony	0.0004	0.1156	0.0219	0.0004	0.2364	0.1600	0.0004	0.4710	0.2000	0.0004	0.4202	0.0792
Tin	0.000921	0.2662	0.0503	0.0004	0.2364	0.1600	0.0004	0.4710	0.2000	0.0004	0.4202	0.0792
Uranium	0.171	49.4164	9.3443	0.0805	47.5746	32.2000	0.0404	47.5691	20.2000	0.0531	55.7826	10.5149
Others	0.0708	20.4624	3.8693	0.0368	21.7632	14.7300	0.0189	22.2197	9.4355	0.0192	20.1332	3.7950
Sum, mg	0.3460	100.0000	14.9859	0.1692	100.0000	52.1844	0.0849	100.0000	32.3335	0.0952	100.0000	14.9507
mg, Filter Loading	1.8300			0.2500			0.2000			0.5050		

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)
NOTE: Species in grey cells are minor impurity contents
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A3.5B.26 Test 3/5 (B) Marple M2 Elemental Analyses, Stages 4-7

3/5 (B)	STAGE 4			STAGE 5			STAGE 6			STAGE 7		
M2	Particle size 6.0 µm			Particle size 3.5 µm			Particle size 1.55 µm			Particle size 0.93 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	0.0111	10.7985		0.0111	10.7985		0.0363	18.6314		0.00803	17.3862	
*Barium	0.00128	1.2452		0.00128	1.2452		0.00114	0.5851		0.00107	2.3167	
*Boron	0.00105	1.0215		0.00105	1.0215		0.00104	0.5338		0.000913	1.9768	
Cerium	0.000313	0.3045	0.7825	0.000313	0.3045	0.0505	0.000097	0.0498	0.0152	0.00002	0.0433	0.0040
Cesium	0.00001	0.0097	0.0250	0.00001	0.0097	0.0016	0.00001	0.0051	0.0016	0.00001	0.0217	0.0020
Chromium	0.000262	0.2549	0.6550	0.000262	0.2549	0.0423	0.000764	0.3921	0.1194	0.000125	0.2706	0.0250
Copper	0.00624	6.0705	15.6000	0.00624	6.0705	1.0065	0.0244	12.5236	3.8125	0.0048	10.3928	0.9600
Europium	0.00002	0.0195	0.0500	0.00002	0.0195	0.0032	0.00002	0.0103	0.0031	0.00002	0.0433	0.0040
Iron	0.0165	16.0518	41.2500	0.0165	16.0518	2.6613	0.0351	18.0155	5.4844	0.00722	15.6324	1.4440
La	0.00002	0.0195	0.0500	0.00002	0.0195	0.0032	0.00002	0.0103	0.0031	0.00002	0.0433	0.0040
Lead	0.000123	0.1197	0.3075	0.000123	0.1197	0.0198	0.000394	0.2022	0.0616	0.000092	0.1992	0.0184
Lithium	0.0002	0.1946	0.5000	0.0002	0.1946	0.0323	0.0002	0.1027	0.0313	0.0002	0.4330	0.0400
*Mg	0.0028	2.7239		0.0028	2.7239		0.00332	1.7040		0.00253	5.4779	
Mn	0.000249	0.2422	0.6225	0.000249	0.2422	0.0402	0.000595	0.3054	0.0930	0.000122	0.2641	0.0244
Mo	0.000031	0.0302	0.0775	0.000031	0.0302	0.0050	0.000082	0.0421	0.0128	0.000023	0.0498	0.0046
Ne	0.00002	0.0195	0.0500	0.00002	0.0195	0.0032	0.00002	0.0103	0.0031	0.00002	0.0433	0.0040
Nickel	0.000222	0.2160	0.5550	0.000222	0.2160	0.0358	0.000523	0.2684	0.0817	0.000121	0.2620	0.0242
Pr	0.00002	0.0195	0.0500	0.00002	0.0195	0.0032	0.00002	0.0103	0.0031	0.00002	0.0433	0.0040
Ruthenium	0.00002	0.0195	0.0500	0.00002	0.0195	0.0032	0.00002	0.0103	0.0031	0.00002	0.0433	0.0040
Samarium	0.00002	0.0195	0.0500	0.00002	0.0195	0.0032	0.00002	0.0103	0.0031	0.00002	0.0433	0.0040
*Strontium	0.0002	0.1946		0.0002	0.1946		0.0002	0.1027		0.0002	0.4330	
Terbium	0.00002	0.0195	0.0500	0.00002	0.0195	0.0032	0.00002	0.0103	0.0031	0.00002	0.0433	0.0040
Titanium	0.0002	0.1946	0.5000	0.0002	0.1946	0.0323	0.0002	0.1027	0.0313	0.0002	0.4330	0.0400
*Zirconium	0.00347	3.3757		0.00347	3.3757		0.00591	3.0334		0.00127	2.7498	
Antimony	0.0004	0.3891	1.0000	0.0004	0.3891	0.0645	0.0004	0.2053	0.0625	0.0004	0.8661	0.0800
Tin	0.000402	0.3911	1.0050	0.000402	0.3911	0.0648	0.000717	0.3680	0.1120	0.0004	0.8661	0.0800
Uranium	0.0576	56.0355	144.0000	0.0576	56.0355	9.2903	0.0833	42.7548	13.0156	0.0183	39.6224	3.6600
Others	0.0209	20.3391	52.2675	0.0209	20.3391	3.3721	0.0415	21.2994	6.4841	0.0110	23.7150	2.1906
Sum, mg	0.1028	100.0000	207.2300	0.1028	100.0000	13.3697	0.1948	100.0000	22.9566	0.0462	100.0000	6.4346
mg, Filter Loading	0.0400			0.6200			0.6400			0.5000		

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)

NOTE: Species in grey cells are minor impurity contents

Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A3.5B.27 Test 3/5 (B) Marple M2 Elemental Analyses, Stages 8-9

3/5 (B)	STAGE 8			STAGE 9		
M2	Particle size 0.52 µm			Particle size final, <0.5 µm		
	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	0.00852	18.2453		0.00399	21.2483	
*Barium	0.00134	2.8696		0.000508	2.7053	
*Boron	0.00108	2.3128		0.0004	2.1302	
Cerium	0.00002	0.0428	0.0077	0.00002	0.1065	0.0182
Cesium	0.00001	0.0214	0.0038	0.00001	0.0533	0.0091
Chromium	0.000136	0.2912	0.0523	0.0001	0.5325	0.0909
Copper	0.00508	10.8786	1.9538	0.00155	8.2543	1.4091
Europium	0.00002	0.0428	0.0077	0.00002	0.1065	0.0182
Iron	0.00705	15.0973	2.7115	0.00268	14.2720	2.4364
La	0.00002	0.0428	0.0077	0.00002	0.1065	0.0182
Lead	0.000092	0.1970	0.0354	0.00005	0.2663	0.0455
Lithium	0.0002	0.4283	0.0769	0.0002	1.0651	0.1818
*Mg	0.00186	3.9831		0.00237	12.6212	
Mn	0.000122	0.2613	0.0469	0.0001	0.5325	0.0909
Mo	0.000021	0.0450	0.0081	0.000012	0.0639	0.0109
Ne	0.00002	0.0428	0.0077	0.00002	0.1065	0.0182
Nickel	0.000116	0.2484	0.0446	0.000067	0.3568	0.0609
Pr	0.00002	0.0428	0.0077	0.00002	0.1065	0.0182
Ruthenium	0.00002	0.0428	0.0077	0.00002	0.1065	0.0182
Samarium	0.00002	0.0428	0.0077	0.00002	0.1065	0.0182
*Strontium	0.0002	0.4283		0.0002	1.0651	
Terbium	0.00002	0.0428	0.0077	0.00002	0.1065	0.0182
Titanium	0.0002	0.4283	0.0769	0.0002	1.0651	0.1818
*Zirconium	0.00141	3.0195		0.000521	2.7745	
Antimony	0.0004	0.8566	0.1538	0.0004	2.1302	0.3636
Tin	0.0004	0.8566	0.1538	0.0004	2.1302	0.3636
Uranium	0.0183	39.1888	7.0385	0.00486	25.8814	4.4182
Others	0.0101	21.6652	3.8912	0.0061	32.4795	5.5445
Sum, mg	0.0467	100.0000	12.4181	0.0188	100.0000	9.8082
mg, Metals Found	0.2600			0.1100		

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)
NOTE: Species in grey cells are minor impurity contents
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A3.5B.28 Test 3/2 (A) LPS L2 Elemental Analyses

	Segment 4		Segment 3		Segment 2		Segment 1		Segment 0	
3/5 (B)	~30-48µm		~48-65µm		~65-82µm		~82-100µm		post-swipe	
L2	mg	% detect	mg	% detect	mg	% detect	mg	% detect	mg	% detect
*Aluminum	0.000917	0.00314	0.000869	0.00168	0.034	0.000917	0.00314	0.000869	0.00168	0.034
*Barium	0.000165	0.000171	0.000169	0.000203	0.00568	0.000165	0.000171	0.000169	0.000203	0.00568
*Boron	0.0004	0.0004	0.0004	0.0004	0.0133	0.0004	0.0004	0.0004	0.0004	0.0133
Cerium	0.000027	0.000037	0.000034	0.000212	0.00117	0.000027	0.000037	0.000034	0.000212	0.00117
Cesium	0.00001	0.00001	0.00001	0.00001	0.000011	0.00001	0.00001	0.00001	0.00001	0.000011
Chromium	0.0001	0.0001	0.0001	0.0001	0.00325	0.0001	0.0001	0.0001	0.0001	0.00325
Copper	0.000353	0.000456	0.000491	0.00136	0.00527	0.000353	0.000456	0.000491	0.00136	0.00527
Europium	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002
Iron	0.00175	0.00206	0.00256	0.00375	0.0388	0.00175	0.00206	0.00256	0.00375	0.0388
La	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002
Lead	0.00005	0.00005	0.00005	0.00005	0.000183	0.00005	0.00005	0.00005	0.00005	0.000183
Lithium	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
*Mg	0.0005	0.000991	0.000707	0.000811	0.0403	0.0005	0.000991	0.000707	0.000811	0.0403
Mn	0.0001	0.0001	0.0001	0.0001	0.00843	0.0001	0.0001	0.0001	0.0001	0.00843
Mo	0.00001	0.00001	0.000011	0.000011	0.0001	0.00001	0.00001	0.000011	0.000011	0.0001
Ne	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002
Nickel	0.00005	0.00005	0.00005	0.000069	0.00202	0.00005	0.00005	0.00005	0.000069	0.00202
Pr	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002
Ruthenium	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002
Samarium	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002
*Strontium	0.0002	0.0002	0.0002	0.0002	0.00188	0.0002	0.0002	0.0002	0.0002	0.00188
Terbium	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002
Titanium	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
*Zirconium	0.000142	0.000172	0.000178	0.000514	0.00152	0.000142	0.000172	0.000178	0.000514	0.00152
Antimony	0.0004	0.000715	0.0004	0.0004	0.0004	0.0004	0.000715	0.0004	0.0004	0.0004
Tin	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
Uranium	0.00318	0.0037	0.00433	0.012	0.0264	0.00318	0.0037	0.00433	0.012	0.0264
Others	0.0033	0.0044	0.0043	0.0056	0.0938	0.0033	0.0044	0.0043	0.0056	0.0938
Sum, mg	0.0093	0.0133	0.0116	0.0228	0.1837	0.0093	0.0133	0.0116	0.0228	0.1837
mg, Filter Loading	0.000917	0.00314	0.000869	0.00168	0.034	0.000917	0.00314	0.000869	0.00168	0.034

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)

NOTE: Species in grey cells are minor impurity contents

Others: Sb, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Sm, Tb, Ti

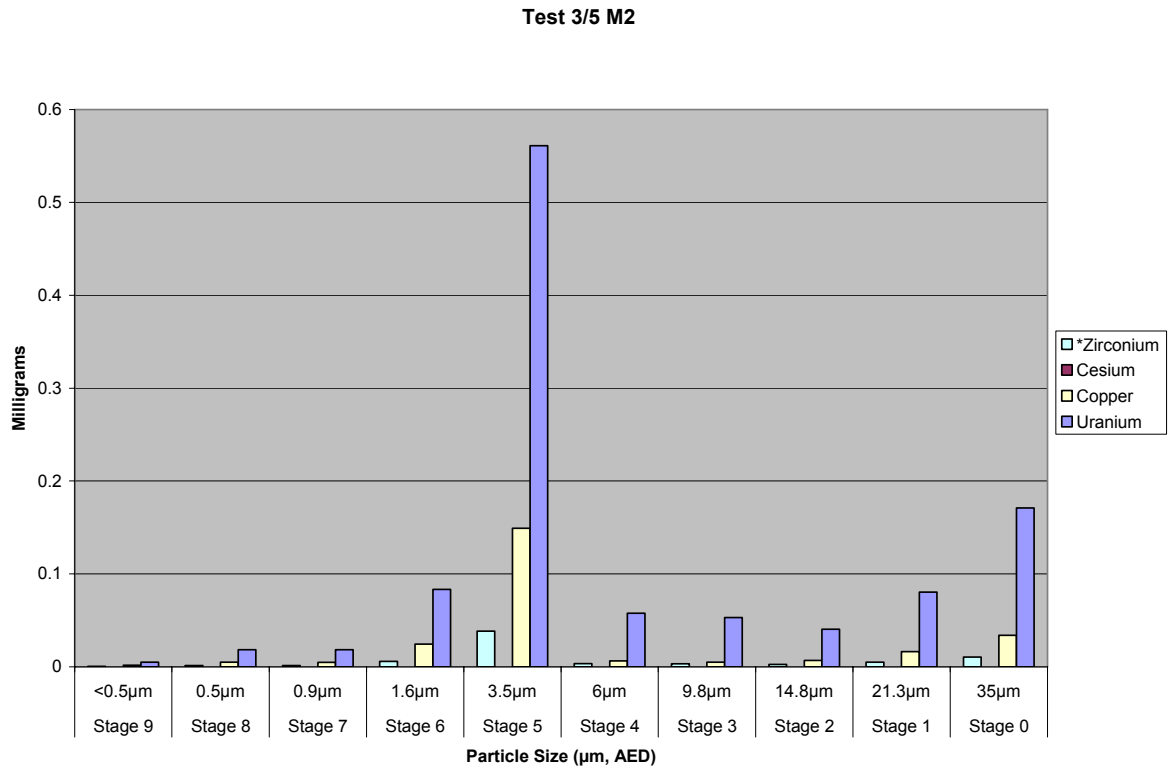


Figure A3.5B.23 Test 3/5 (B) Marple M2 Metals Analysis Distribution, mg

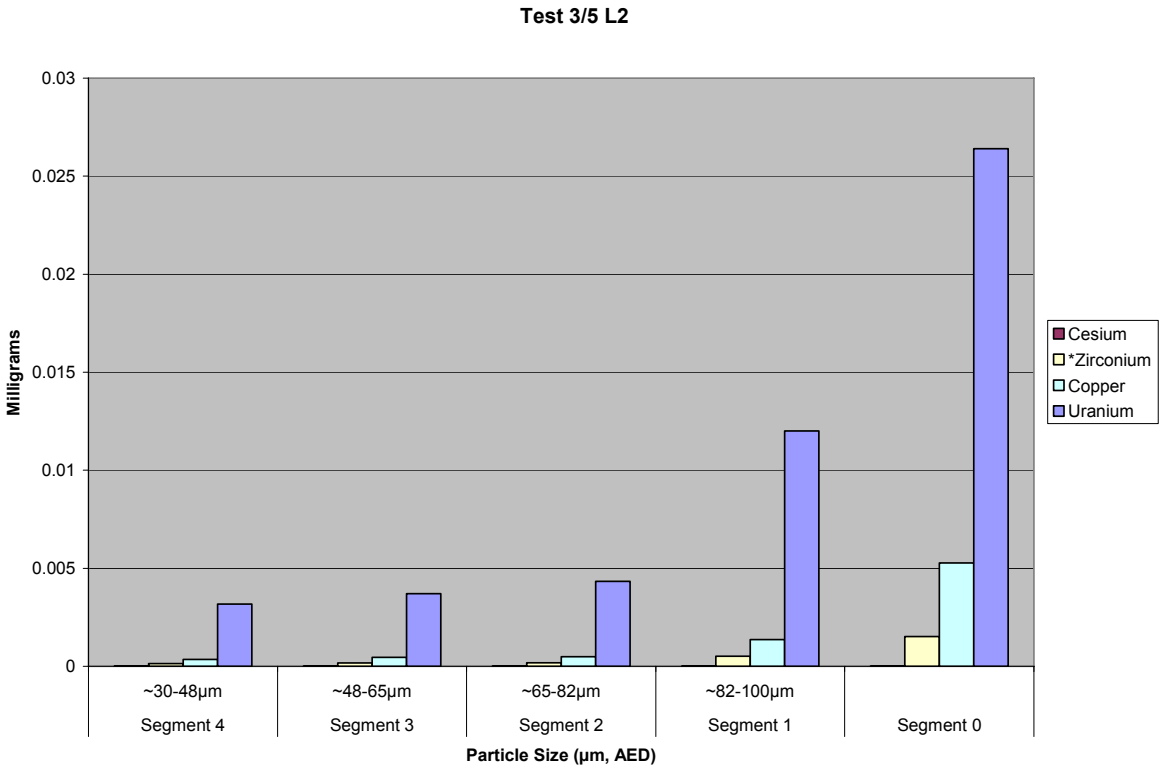


Figure A3.5B.24 Test 3/5 (B) LPS L2 Metals Analysis Distribution, mg

Table A3.5B.29 Test 3/5 (B) Marple M3 Elemental Analyses, Stages 0-3

3/5 (B)	STAGE 0			STAGE 1			STAGE 2			STAGE 3		
M3	Particle size 35 µm			Particle size 21.3 µm			Particle size 14.8 µm			Particle size 9.8 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	0.0574	21.8841		0.0222	17.5115		0.0112	16.8972		0.011	10.9238	0.0574
*Barium	0.00105	0.4003		0.0145	11.4377		0.00122	1.8406		0.00147	1.4598	0.00105
*Boron	0.000671	0.2558		0.011	8.6769		0.00125	1.8859		0.00131	1.3009	0.000671
Cerium	0.000372	0.1418	0.0058	0.000157	0.1238	0.3140	0.00011	0.1660		0.000298	0.2959	0.000372
Cesium	0.00001	0.0038	0.0002	0.00001	0.0079	0.0200	0.00001	0.0151		0.00001	0.0099	0.00001
Chromium	0.00119	0.4537	0.0186	0.000259	0.2043	0.5180	0.000172	0.2595		0.000262	0.2602	0.00119
Copper	0.0332	12.6577	0.5196	0.00858	6.7679	17.1600	0.00571	8.6146		0.0062	6.1570	0.0332
Europium	0.00002	0.0076	0.0003	0.00002	0.0158	0.0400	0.00002	0.0302		0.00002	0.0199	0.00002
Iron	0.069	26.3067	1.0798	0.0154	12.1476	30.8000	0.0101	15.2377		0.0164	16.2863	0.069
La	0.00002	0.0076	0.0003	0.00002	0.0158	0.0400	0.00002	0.0302		0.00002	0.0199	0.00002
Lead	0.000611	0.2329	0.0096	0.000158	0.1246	0.3160	0.000111	0.1675		0.000111	0.1102	0.000611
Lithium	0.0002	0.0763	0.0031	0.0002	0.1578	0.4000	0.0002	0.3017		0.0002	0.1986	0.0002
*Mg	0.00382	1.4564		0.0031	2.4453		0.00165	2.4893		0.00302	2.9991	0.00382
Mn	0.00109	0.4156	0.0171	0.000258	0.2035	0.5160	0.000169	0.2550		0.000226	0.2244	0.00109
Mo	0.000143	0.0545	0.0022	0.000036	0.0284	0.0720	0.000026	0.0392		0.000086	0.0854	0.000143
Ne	0.00002	0.0076	0.0003	0.00002	0.0158	0.0400	0.00002	0.0302		0.00002	0.0199	0.00002
Nickel	0.000879	0.3351	0.0138	0.000311	0.2453	0.6220	0.000245	0.3696		0.000195	0.1936	0.000879
Pr	0.00002	0.0076	0.0003	0.00002	0.0158	0.0400	0.00002	0.0302		0.00002	0.0199	0.00002
Ruthenium	0.00002	0.0076	0.0003	0.00002	0.0158	0.0400	0.00002	0.0302		0.00002	0.0199	0.00002
Samarium	0.00002	0.0076	0.0003	0.00002	0.0158	0.0400	0.00002	0.0302		0.00002	0.0199	0.00002
*Strontium	0.0002	0.0763		0.0002	0.1578		0.0002	0.3017		0.0002	0.1986	0.0002
Terbium	0.00002	0.0076	0.0003	0.00002	0.0158	0.0400	0.00002	0.0302		0.00002	0.0199	0.00002
Titanium	0.000203	0.0774	0.0032	0.0002	0.1578	0.4000	0.0002	0.3017		0.0002	0.1986	0.000203
*Zirconium	0.01	3.8126		0.00284	2.2402		0.00197	2.9721		0.00317	3.1480	0.01
Antimony	0.000562	0.2143	0.0088	0.0004	0.3155	0.8000	0.0004	0.6035		0.0004	0.3972	0.000562
Tin	0.00085	0.3241	0.0133	0.000525	0.4141	1.0500	0.0004	0.6035		0.0004	0.3972	0.00085
Uranium	0.0807	30.7674	1.2629	0.0463	36.5217	92.6000	0.0308	46.4674		0.0554	55.0160	0.0807
Others	0.0776	29.5923	1.2147	0.0202	15.9670	40.4840	0.0132	19.9040		0.0210	20.8743	0.0776
Sum, mg	0.2623	100.0000	2.9601	0.1268	100.0000	145.8680	0.0663	100.0000	0.0000	0.1007	100.0000	0.2623
mg, Filter Loading	6.3900			0.0500			-0.0800			-0.1300		6.3900

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)

NOTE: Species in grey cells are minor impurity contents

Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A3.5B.30 Test 3/5 (B) Marple M3 Elemental Analyses, Stages 4-7

3/5 (B)	STAGE 4			STAGE 5			STAGE 6			STAGE 7		
M3	Particle size 6.0 µm			Particle size 3.5 µm			Particle size 1.55 µm			Particle size 0.93 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	0.0121	11.3466		0.254	19.3820		0.0555	16.3651		0.0127	11.4021	
*Barium	0.00121	1.1347		0.00101	0.0771		0.000982	0.2896		0.00109	0.9786	
*Boron	0.00102	0.9565		0.000885	0.0675		0.000733	0.2161		0.000843	0.7568	
Cerium	0.000324	0.3038		0.00096	0.0733		0.000168	0.0495		0.000511	0.4588	
Cesium	0.00001	0.0094		0.00001	0.0008		0.00001	0.0029		0.00001	0.0090	
Chromium	0.000328	0.3076		0.00518	0.3953		0.00116	0.3420		0.00022	0.1975	
Copper	0.00639	5.9921		0.154	11.7513		0.045	13.2690		0.0116	10.4145	
Europium	0.00002	0.0188		0.00002	0.0015		0.00002	0.0059		0.00002	0.0180	
Iron	0.0157	14.7224		0.231	17.6269		0.0546	16.0997		0.0141	12.6590	
La	0.00002	0.0188		0.00002	0.0015		0.00002	0.0059		0.00002	0.0180	
Lead	0.000109	0.1022		0.00226	0.1725		0.000549	0.1619		0.00012	0.1077	
Lithium	0.0002	0.1875		0.0002	0.0153		0.0002	0.0590		0.0002	0.1796	
*Mg	0.0039	3.6572		0.00544	0.4151		0.00441	1.3004		0.00202	1.8136	
Mn	0.000227	0.2129		0.00385	0.2938		0.000883	0.2604		0.00022	0.1975	
Mo	0.000041	0.0384		0.000481	0.0367		0.000127	0.0374		0.000031	0.0278	
Ne	0.00002	0.0188		0.000024	0.0018		0.00002	0.0059		0.00002	0.0180	
Nickel	0.000219	0.2054		0.00358	0.2732		0.000764	0.2253		0.000198	0.1778	
Pr	0.00002	0.0188		0.00002	0.0015		0.00002	0.0059		0.00002	0.0180	
Ruthenium	0.00002	0.0188		0.00002	0.0015		0.00002	0.0059		0.00002	0.0180	
Samarium	0.00002	0.0188		0.00002	0.0015		0.00002	0.0059		0.00002	0.0180	
*Strontium	0.0002	0.1875		0.0002	0.0153		0.0002	0.0590		0.0002	0.1796	
Terbium	0.00002	0.0188		0.00002	0.0015		0.00002	0.0059		0.00002	0.0180	
Titanium	0.0002	0.1875		0.000417	0.0318		0.000201	0.0593		0.0002	0.1796	
*Zirconium	0.00341	3.1977		0.0392	2.9912		0.0109	3.2140		0.00279	2.5049	
Antimony	0.000612	0.5739		0.0004	0.0305		0.0004	0.1179		0.00059	0.5297	
Tin	0.0004	0.3751		0.00528	0.4029		0.00121	0.3568		0.0004	0.3591	
Uranium	0.0599	56.1703		0.602	45.9368		0.161	47.4734		0.0632	56.7412	
Others	0.0215	20.1200		0.2527	19.2852		0.0632	18.6397		0.0178	15.9980	
Sum, mg	0.1066	100.0000	0.0000	1.3105	100.0000	0.0000	0.3391	100.0000	0.0000	0.1114	100.0000	0.0000
mg, Filter Loading	-0.3700			-0.0300			-0.0900			-0.3300		

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)

NOTE: Species in grey cells are minor impurity contents

Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A3.5B.31 Test 3/5 (B) Marple M3 Elemental Analyses, Stages 8-9

3/5 (B)	STAGE 8			STAGE 9		
M3	Particle size 0.52 µm			Particle size final, <0.5 µm		
	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	0.00798	15.4501		0.00267	16.8582	
*Barium	0.000998	1.9322		0.00042	2.6518	
*Boron	0.000748	1.4482		0.000682	4.3061	
Cerium	0.000021	0.0407		0.00002	0.1263	
Cesium	0.00001	0.0194		0.00001	0.0631	
Chromium	0.000136	0.2633		0.000158	0.9976	
Copper	0.0067	12.9719		0.00175	11.0494	
Europium	0.00002	0.0387		0.00002	0.1263	
Iron	0.00714	13.8238		0.001	6.3139	
La	0.00002	0.0387		0.00002	0.1263	
Lead	0.000083	0.1607		0.00005	0.3157	
Lithium	0.0002	0.3872		0.0002	1.2628	
*Mg	0.00243	4.7047		0.00185	11.6808	
Mn	0.000117	0.2265		0.0001	0.6314	
Mo	0.000022	0.0426		0.00001	0.0631	
Ne	0.00002	0.0387		0.00002	0.1263	
Nickel	0.000115	0.2227		0.000052	0.3283	
Pr	0.00002	0.0387		0.00002	0.1263	
Ruthenium	0.00002	0.0387		0.00002	0.1263	
Samarium	0.00002	0.0387		0.00002	0.1263	
*Strontium	0.0002	0.3872		0.0002	1.2628	
Terbium	0.00002	0.0387		0.00002	0.1263	
Titanium	0.0002	0.3872		0.0002	1.2628	
*Zirconium	0.00171	3.3107		0.000507	3.2012	
Antimony	0.0004	0.7744		0.000659	4.1609	
Tin	0.0004	0.7744		0.0004	2.5256	
Uranium	0.0219	42.4008		0.00476	30.0543	
Others	0.0108	20.8383		0.0042	26.5122	
Sum, mg	0.0517	100.0000	0.0000	0.0158	100.0000	0.0000
mg, Metals Found	-0.2100			-0.0700		

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)
NOTE: Species in grey cells are minor impurity contents
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A3.5B.32 Test 3/2 (A) LPS L3 Elemental Analyses

	Segment 4		Segment 3		Segment 2		Segment 1		Segment 0	
3/5 (B)	~30-48µm		~48-65µm		~65-82µm		~82-100µm		post-swipe	
L3	mg	% detect	mg	% detect	mg	% detect	mg	% detect	mg	% detect
*Aluminum	0.00145	9.3548	0.000812	7.0732	0.00119	6.8596	0.00497	4.8373	0.0119	5.1795
*Barium	0.000606	3.9097	0.000398	3.4669	0.000279	1.6083	0.00048	0.4672	0.00641	2.7900
*Boron	0.000499	3.2194	0.0004	3.4843	0.0004	2.3057	0.000444	0.4321	0.0162	7.0511
Cerium	0.000142	0.9161	0.000084	0.7317	0.000105	0.6053	0.00091	0.8857	0.00841	3.6605
Cesium	0.00001	0.0645	0.00001	0.0871	0.00001	0.0576	0.00001	0.0097	0.000149	0.0649
Chromium	0.000189	1.2194	0.000174	1.5157	0.000216	1.2451	0.000533	0.5188	0.00447	1.9456
Copper	0.000994	6.4129	0.000801	6.9774	0.00127	7.3207	0.00609	5.9274	0.0258	11.2295
Europium	0.00002	0.1290	0.00002	0.1742	0.00002	0.1153	0.00002	0.0195	0.000075	0.0326
Iron	0.00294	18.9677	0.00159	13.8502	0.00273	15.7367	0.0158	15.3782	0.0643	27.9866
La	0.00002	0.1290	0.00002	0.1742	0.00002	0.1153	0.00002	0.0195	0.00011	0.0479
Lead	0.00005	0.3226	0.00005	0.4355	0.00005	0.2882	0.000081	0.0788	0.000231	0.1005
Lithium	0.0002	1.2903	0.0002	1.7422	0.0002	1.1529	0.0002	0.1947	0.0002	0.0871
*Mg	0.0013	8.3871	0.0005	4.3554	0.000528	3.0436	0.000637	0.6200	0.0383	16.6701
Mn	0.0001	0.6452	0.0001	0.8711	0.0001	0.5764	0.000194	0.1888	0.00961	4.1828
Mo	0.00001	0.0645	0.00001	0.0871	0.00001	0.0576	0.00002	0.0195	0.000163	0.0709
Ne	0.00002	0.1290	0.00002	0.1742	0.00002	0.1153	0.00002	0.0195	0.000242	0.1053
Nickel	0.00005	0.3226	0.00005	0.4355	0.00005	0.2882	0.000184	0.1791	0.00258	1.1229
Pr	0.00002	0.1290	0.00002	0.1742	0.00002	0.1153	0.00002	0.0195	0.00002	0.0087
Ruthenium	0.00002	0.1290	0.00002	0.1742	0.00002	0.1153	0.00002	0.0195	0.000059	0.0257
Samarium	0.00002	0.1290	0.00002	0.1742	0.00002	0.1153	0.00002	0.0195	0.00002	0.0087
*Strontium	0.0002	1.2903	0.0002	1.7422	0.0002	1.1529	0.0002	0.1947	0.00176	0.7660
Terbium	0.00002	0.1290	0.00002	0.1742	0.00002	0.1153	0.00002	0.0195	0.00002	0.0087
Titanium	0.0002	1.2903	0.0002	1.7422	0.0002	1.1529	0.0002	0.1947	0.000334	0.1454
*Zirconium	0.00028	1.8065	0.000221	1.9251	0.00036	2.0752	0.00325	3.1632	0.00289	1.2579
Antimony	0.0004	2.5806	0.0004	3.4843	0.0004	2.3057	0.0004	0.3893	0.0004	0.1741
Tin	0.0004	2.5806	0.0004	3.4843	0.0004	2.3057	0.0004	0.3893	0.0004	0.1741
Uranium	0.00534	34.4516	0.00474	41.2892	0.00851	49.0546	0.0676	65.7952	0.0347	15.1032
Others	0.0054	34.5742	0.0032	27.8223	0.0044	25.3862	0.0182	17.6839	0.1209	52.6108
Sum, mg	0.0155	100.0000	0.0115	100.0000	0.0173	100.0000	0.1027	100.0000	0.2298	100.0000
mg, Filter Loading										

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)
NOTE: Species in grey cells are minor impurity contents
Others: Sb, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Sm, Tb, Ti

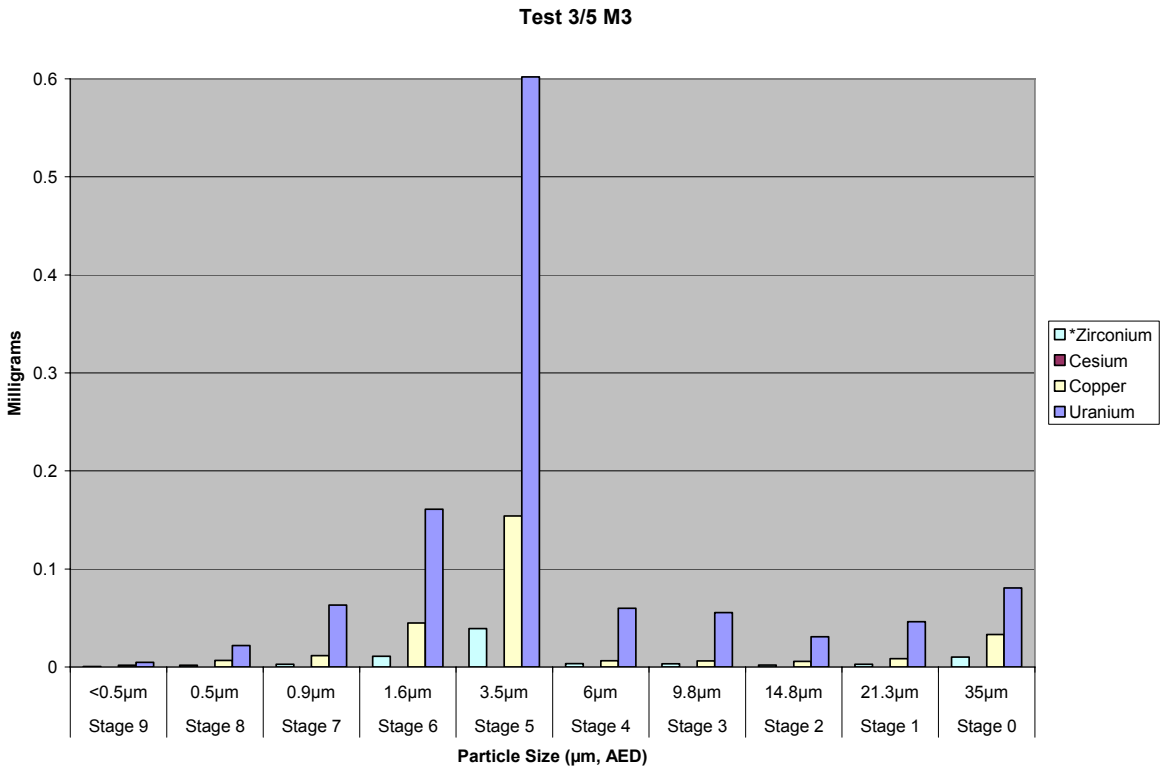


Figure A3.5B.25 Test 3/5 (B) Marple M3 Metals Analysis Distribution, mg

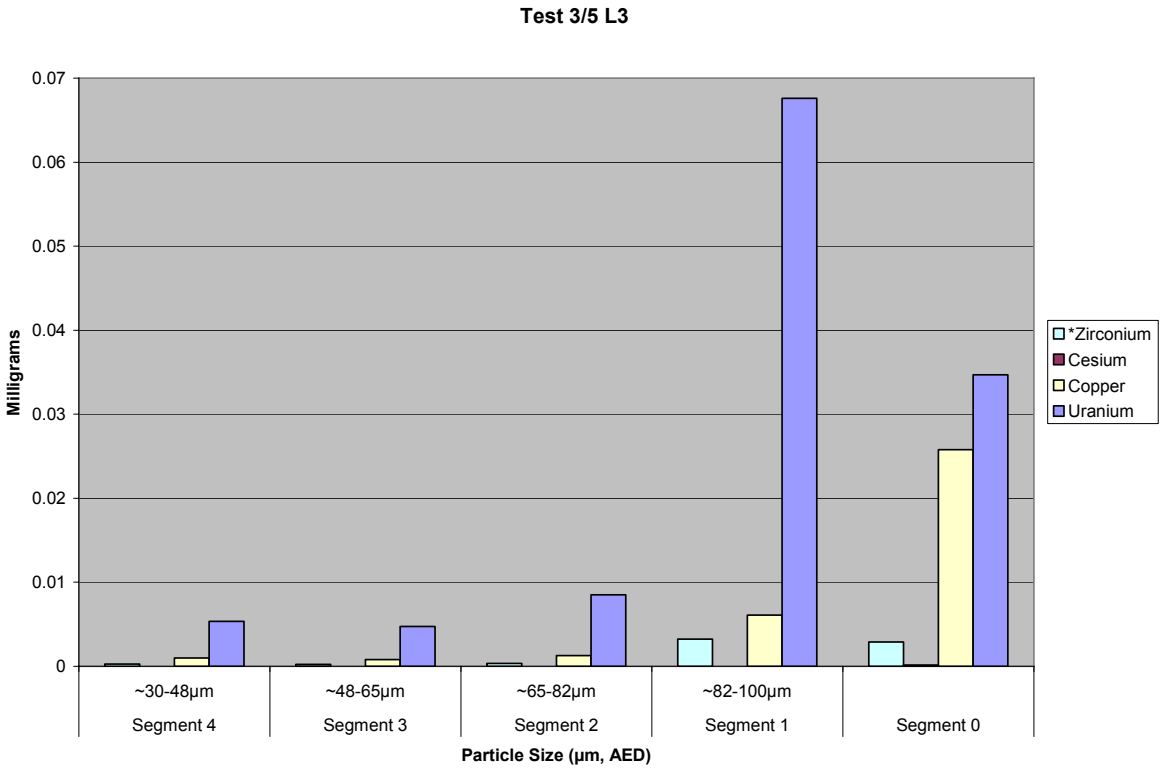


Figure A3.5B.26 Test 3/5 (B) LPS L3 Metals Analysis Distribution, mg

Table A3.5B.33 Test 3/5 (B) Marple M4 Elemental Analyses, Stages 0-3

3/5 (B)	STAGE 0			STAGE 1			STAGE 2			STAGE 3		
M4	Particle size 35 µm			Particle size 21.3 µm			Particle size 14.8 µm			Particle size 9.8 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	0.0466	16.9030		0.0313	17.8833		0.013	17.9192		0.0124	11.5795	
*Barium	0.00106	0.3845		0.00126	0.7199		0.00111	1.5300		0.00101	0.9432	
*Boron	0.000946	0.3431		0.00112	0.6399		0.000991	1.3660		0.000987	0.9217	
Cerium	0.000326	0.1182	0.0126	0.000232	0.1326	0.0455	0.00012	0.1654		0.000325	0.3035	0.1912
Cesium	0.00001	0.0036	0.0004	0.00001	0.0057	0.0020	0.00001	0.0138		0.00001	0.0093	0.0059
Chromium	0.00104	0.3772	0.0402	0.000764	0.4365	0.1498	0.00034	0.4687		0.000389	0.3633	0.2288
Copper	0.029	10.5190	1.1197	0.0175	9.9986	3.4314	0.006	8.2704		0.00616	5.7524	3.6235
Europium	0.00002	0.0073	0.0008	0.00002	0.0114	0.0039	0.00002	0.0276		0.00002	0.0187	0.0118
Iron	0.0458	16.6128	1.7683	0.0287	16.3978	5.6275	0.0108	14.8867		0.0152	14.1942	8.9412
La	0.00002	0.0073	0.0008	0.00002	0.0114	0.0039	0.00002	0.0276		0.00002	0.0187	0.0118
Lead	0.000534	0.1937	0.0206	0.000342	0.1954	0.0671	0.000126	0.1737		0.000129	0.1205	0.0759
Lithium	0.0002	0.0725	0.0036	0.0002	0.1143	0.0392	0.0002	0.2757		0.0002	0.1868	0.1176
*Mg	0.00264	0.9576		0.00427	2.4397		0.00351	4.8382		0.00352	3.2871	
Mn	0.00119	0.4316	0.0459	0.000511	0.2920	0.1002	0.000191	0.2633		0.000235	0.2194	0.1382
Mo	0.000116	0.0421	0.0045	0.000096	0.0548	0.0188	0.000034	0.0469		0.000026	0.0243	0.0153
Ne	0.00002	0.0073	0.0008	0.00002	0.0114	0.0039	0.00002	0.0276		0.00002	0.0187	0.0118
Nickel	0.000688	0.2496	0.0266	0.000439	0.2508	0.0861	0.000156	0.2150		0.00018	0.1681	0.1059
Pr	0.00002	0.0073	0.0008	0.00002	0.0114	0.0039	0.00002	0.0276		0.00002	0.0187	0.0118
Ruthenium	0.00002	0.0073	0.0008	0.00002	0.0114	0.0039	0.00002	0.0276		0.00002	0.0187	0.0118
Samarium	0.00002	0.0073	0.0008	0.00002	0.0114	0.0039	0.00002	0.0276		0.00002	0.0187	0.0118
*Strontium	0.0002	0.0725		0.0002	0.1143		0.0002	0.2757		0.0002	0.1868	
Terbium	0.00002	0.0073	0.0004	0.00002	0.0114	0.0039	0.00002	0.0276		0.00002	0.0187	0.0118
Titanium	0.0002	0.0725	0.0077	0.0002	0.1143	0.0392	0.0002	0.2757		0.0002	0.1868	0.1176
*Zirconium	0.00966	3.5039		0.00579	3.3081		0.00232	3.1979		0.00396	3.6980	
Antimony	0.0004	0.1451	0.0154	0.0004	0.2285	0.0784	0.0004	0.5514		0.000815	0.7611	0.4794
Tin	0.000941	0.3413	0.0363	0.00075	0.4285	0.1471	0.0004	0.5514		0.0004	0.3735	0.2353
Uranium	0.134	48.6051	5.1737	0.0808	46.1651	15.8431	0.0323	44.5222		0.0606	56.5900	35.6471
Others	0.0527	19.1258	2.0358	0.0358	20.4783	7.0278	0.0159	21.8848		0.0208	19.4367	12.2435
Sum, mg	0.2757	100.0000	8.2806	0.1750	100.0000	25.7027	0.0725	100.0000	0.0000	0.1071	100.0000	50.0053
mg, Filter Loading	2.5900			0.5100			-0.0900			0.1700		

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)
NOTE: Species in grey cells are minor impurity contents
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A3.5B.34 Test 3/5 (B) Marple M4 Elemental Analyses, Stages 4-7

3/5 (B)	STAGE 4			STAGE 5			STAGE 6			STAGE 7		
M4	Particle size 6.0 µm			Particle size 3.5 µm			Particle size 1.55 µm			Particle size 0.93 µm		
	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	0.0149	13.4502		0.31	22.4804		0.079	19.3582		0.0244	18.1494	
*Barium	0.000932	0.8413		0.000949	0.0688		0.000887	0.2174		0.001	0.7438	
*Boron	0.000912	0.8233		0.00096	0.0696		0.000906	0.2220		0.000995	0.7401	
Cerium	0.000306	0.2762	0.1133	0.000811	0.0588	0.0504	0.00038	0.0931	0.0469	0.000045	0.0335	0.0094
Cesium	0.00001	0.0090	0.0037	0.00001	0.0007	0.0006	0.000048	0.0118	0.0059	0.00001	0.0074	0.0021
Chromium	0.00038	0.3430	0.1407	0.00512	0.3713	0.3180	0.00144	0.3529	0.1778	0.000541	0.4024	0.1127
Copper	0.00727	6.5626	2.6926	0.15	10.8776	9.3168	0.0497	12.1785	6.1358	0.0164	12.1988	3.4167
Europium	0.00002	0.0181	0.0074	0.00002	0.0015	0.0012	0.00002	0.0049	0.0025	0.00002	0.0149	0.0042
Iron	0.0153	13.8113	5.6667	0.243	17.6217	15.0932	0.0678	16.6138	8.3704	0.0207	15.3972	4.3125
La	0.00002	0.0181	0.0074	0.00002	0.0015	0.0012	0.00002	0.0049	0.0025	0.00002	0.0149	0.0042
Lead	0.000157	0.1417	0.0581	0.00254	0.1842	0.1578	0.000821	0.2012	0.1014	0.00027	0.2008	0.0563
Lithium	0.0002	0.1805	0.0741	0.0002	0.0145	0.0124	0.0002	0.0490	0.0247	0.0002	0.1488	0.0417
*Mg	0.00219	1.9769		0.00633	0.4590		0.00301	0.7376		0.00204	1.5174	
Mn	0.000255	0.2302	0.0944	0.00413	0.2995	0.2565	0.00118	0.2891	0.1457	0.000376	0.2797	0.0783
Mo	0.00003	0.0271	0.0111	0.00054	0.0392	0.0335	0.000179	0.0439	0.0221	0.000057	0.0424	0.0119
Ne	0.00002	0.0181	0.0074	0.00002	0.0015	0.0012	0.00002	0.0049	0.0025	0.00002	0.0149	0.0042
Nickel	0.000196	0.1769	0.0726	0.00385	0.2792	0.2391	0.000974	0.2387	0.1202	0.000318	0.2365	0.0663
Pr	0.00002	0.0181	0.0074	0.00002	0.0015	0.0012	0.00002	0.0049	0.0025	0.00002	0.0149	0.0042
Ruthenium	0.00002	0.0181	0.0074	0.00002	0.0015	0.0012	0.00002	0.0049	0.0025	0.00002	0.0149	0.0042
Samarium	0.00002	0.0181	0.0074	0.00002	0.0015	0.0012	0.00002	0.0049	0.0025	0.00002	0.0149	0.0042
*Strontium	0.0002	0.1805		0.0002	0.0145		0.0002	0.0490		0.0002	0.1488	
Terbium	0.00002	0.0181	0.0074	0.00002	0.0015	0.0012	0.00002	0.0049	0.0025	0.00002	0.0149	0.0042
Titanium	0.0002	0.1805	0.0741	0.000421	0.0305	0.0261	0.0002	0.0490	0.0247	0.0002	0.1488	0.0417
*Zirconium	0.0042	3.7913		0.0434	3.1473		0.0139	3.4061		0.00468	3.4811	
Antimony	0.0004	0.3611	0.1481	0.0004	0.0290	0.0248	0.00057	0.1397	0.0704	0.0004	0.2975	0.0833
Tin	0.000501	0.4523	0.1856	0.00398	0.2886	0.2472	0.00156	0.3823	0.1926	0.000768	0.5713	0.1600
Uranium	0.0621	56.0576	23.0000	0.602	43.6554	37.3913	0.185	45.3326	22.8395	0.0607	45.1503	12.6458
Others	0.0192	17.3571	7.1215	0.2665	19.3223	16.5498	0.0763	18.6952	9.4190	0.0250	18.6120	5.2129
Sum, mg	0.1108	100.0000	32.3870	1.3790	100.0000	63.1765	0.4081	100.0000	38.2953	0.1344	100.0000	21.0677
mg, Filter Loading	0.2700			1.6100			0.8100			0.4800		

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)

NOTE: Species in grey cells are minor impurity contents

Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A3.5B.35 Test 3/5 (B) Marple M4 Elemental Analyses, Stages 8-9

3/5 (B)	STAGE 8			STAGE 9		
M4	Particle size 0.52 µm			Particle size final, <0.5 µm		
	mg	% detect	% loading	mg	% detect	% loading
*Aluminum	0.0235	16.6165		0.00502	20.7070	
*Barium	0.00101	0.7142		0.000574	2.3677	
*Boron	0.000849	0.6003		0.000432	1.7820	
Cerium	0.000049	0.0346	0.0288	0.00002	0.0825	
Cesium	0.00001	0.0071	0.0059	0.00001	0.0412	
Chromium	0.000564	0.3988	0.3318	0.000183	0.7549	
Copper	0.0175	12.3740	10.2941	0.00283	11.6735	
Europium	0.00002	0.0141	0.0118	0.00002	0.0825	
Iron	0.0218	15.4144	12.8235	0.00197	8.1261	
La	0.00002	0.0141	0.0118	0.00002	0.0825	
Lead	0.000287	0.2029	0.1688	0.000052	0.2145	
Lithium	0.0002	0.1414	0.1176	0.0002	0.8250	
*Mg	0.00241	1.7041		0.00176	7.2598	
Mn	0.000397	0.2807	0.2335	0.0001	0.4125	
Mo	0.000063	0.0445	0.0371	0.00001	0.0412	
Ne	0.00002	0.0141	0.0118	0.00002	0.0825	
Nickel	0.000313	0.2213	0.1841	0.000081	0.3341	
Pr	0.00002	0.0141	0.0118	0.00002	0.0825	
Ruthenium	0.00002	0.0141	0.0118	0.00002	0.0825	
Samarium	0.00002	0.0141	0.0118	0.00002	0.0825	
*Strontium	0.0002	0.1414		0.0002	0.8250	
Terbium	0.00002	0.0141	0.0118	0.00002	0.0825	
Titanium	0.0002	0.1414	0.1176	0.0002	0.8250	
*Zirconium	0.00547	3.8677		0.000991	4.0878	
Antimony	0.000417	0.2949	0.2453	0.0004	1.6500	
Tin	0.000647	0.4575	0.3806	0.0004	1.6500	
Uranium	0.0654	46.2433	38.4706	0.00867	35.7629	
Others	0.0266	18.7879	15.6300	0.0049	20.1130	
Sum, mg	0.1414	100.0000	63.5218	0.0242	100.0000	0.0000
mg, Metals Found	0.1700			-0.0400		

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)
NOTE: Species in grey cells are minor impurity contents
Others: Sb, Cs, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Ru, Sm, Sr, Tb, Ti

Table A3.5B.36 Test 3/2 (A) LPS L4 Elemental Analyses

	Segment 4		Segment 3		Segment 2		Segment 1		Segment 0	
3/5 (B)	~30-48µm		~48-65µm		~65-82µm		~82-100µm		post-swipe	
L4	mg	% detect	mg	% detect	mg	% detect	mg	% detect	mg	% detect
*Aluminum	0.00107	8.4672	0.00104	8.7380	0.000815	5.1700	0.0041	5.1237	0.00692	4.3198
*Barium	0.000222	1.7567	0.000186	1.5628	0.000137	0.8691	0.000322	0.4024	0.00376	2.3472
*Boron	0.0004	3.1653	0.0004	3.3608	0.0004	2.5374	0.0004	0.4999	0.0158	9.8632
Cerium	0.00009	0.7122	0.000098	0.8234	0.000153	0.9706	0.000499	0.6236	0.00499	3.1150
Cesium	0.00001	0.0791	0.00001	0.0840	0.00001	0.0634	0.00001	0.0125	0.000057	0.0356
Chromium	0.000216	1.7093	0.000201	1.6888	0.000234	1.4844	0.000465	0.5811	0.00339	2.1162
Copper	0.000729	5.7688	0.000638	5.3604	0.00082	5.2017	0.00379	4.7363	0.0133	8.3026
Europium	0.00002	0.1583	0.00002	0.1680	0.00002	0.1269	0.00002	0.0250	0.000038	0.0237
Iron	0.00223	17.6466	0.00122	10.2504	0.00154	9.7691	0.00946	11.8219	0.0398	24.8453
La	0.00002	0.1583	0.00002	0.1680	0.00002	0.1269	0.00002	0.0250	0.000068	0.0424
Lead	0.00005	0.3957	0.00005	0.4201	0.00005	0.3172	0.000052	0.0650	0.00015	0.0936
Lithium	0.0002	1.5827	0.0002	1.6804	0.0002	1.2687	0.0002	0.2499	0.0002	0.1249
*Mg	0.0005	3.9566	0.0005	4.2010	0.000754	4.7830	0.0005	0.6248	0.0216	13.4839
Mn	0.0001	0.7913	0.0001	0.8402	0.0001	0.6344	0.000135	0.1687	0.00584	3.6456
Mo	0.00001	0.0791	0.00001	0.0840	0.00001	0.0634	0.000015	0.0187	0.000102	0.0637
Ne	0.00002	0.1583	0.00002	0.1680	0.00002	0.1269	0.00002	0.0250	0.000046	0.0287
Nickel	0.00005	0.3957	0.00005	0.4201	0.00005	0.3172	0.000133	0.1662	0.00202	1.2610
Pr	0.00002	0.1583	0.00002	0.1680	0.00002	0.1269	0.00002	0.0250	0.00002	0.0125
Ruthenium	0.00002	0.1583	0.00002	0.1680	0.00002	0.1269	0.00002	0.0250	0.000024	0.0150
Samarium	0.00002	0.1583	0.00002	0.1680	0.00002	0.1269	0.00002	0.0250	0.00002	0.0125
*Strontium	0.0002	1.5827	0.0002	1.6804	0.0002	1.2687	0.0002	0.2499	0.00137	0.8552
Terbium	0.00002	0.1583	0.00002	0.1680	0.00002	0.1269	0.00002	0.0250	0.00002	0.0125
Titanium	0.0002	1.5827	0.0002	1.6804	0.0002	1.2687	0.0002	0.2499	0.000206	0.1286
*Zirconium	0.00029	2.2948	0.000339	2.8483	0.000491	3.1147	0.0028	3.4991	0.00265	1.6543
Antimony	0.0004	3.1653	0.0004	3.3608	0.0004	2.5374	0.0004	0.4999	0.0004	0.2497
Tin	0.0004	3.1653	0.0004	3.3608	0.0004	2.5374	0.0004	0.4999	0.0004	0.2497
Uranium	0.00513	40.5951	0.00552	46.3788	0.00866	54.9353	0.0558	69.7317	0.037	23.0974
Others	0.0039	30.6718	0.0029	23.9540	0.0035	21.9361	0.0115	14.3462	0.0737	46.0201
Sum, mg	0.0126	100.0000	0.0119	100.0000	0.0158	100.0000	0.0800	100.0000	0.1602	100.0000
mg, Filter Loading										

*High Aluminum, Barium, Boron, Magnesium, Strontium, Zirconium content due to filter blank content (not included in loading)
NOTE: Species in grey cells are minor impurity contents
Others: Sb, Cr, Eu, Fe, La, Pb, Mg, Mn, Mo, Nd, Ni, Pr, Sm, Tb, Ti

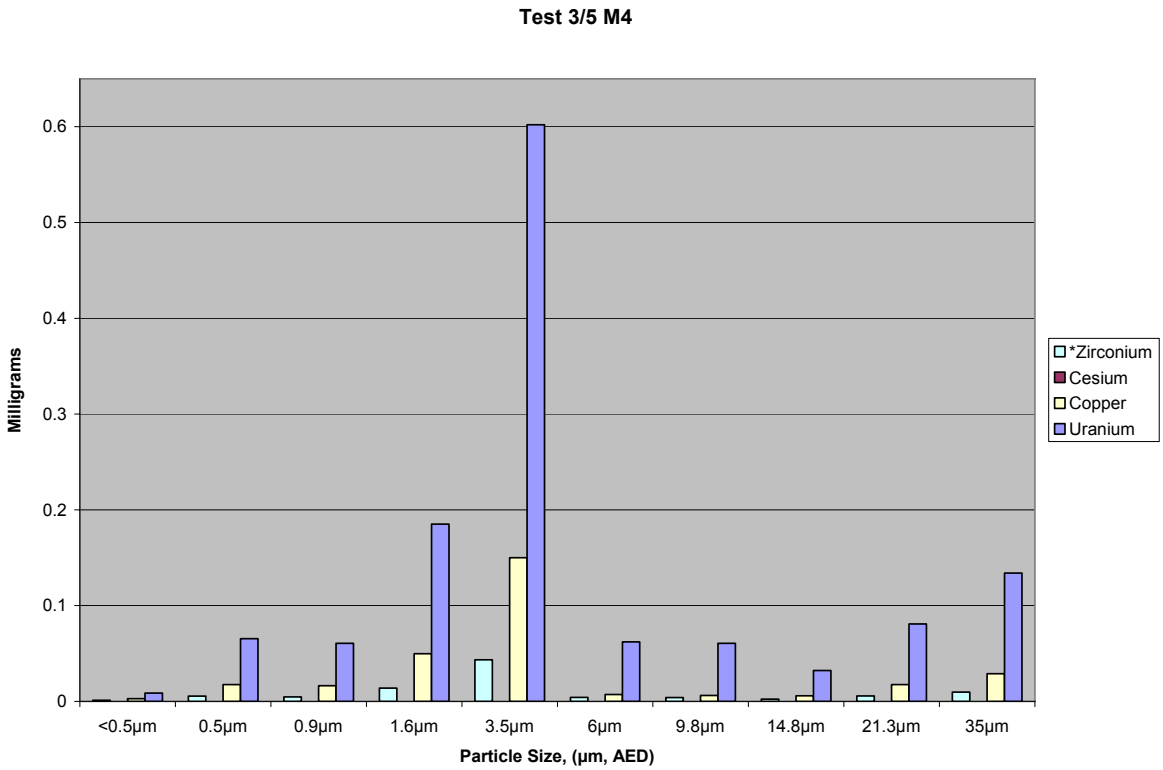


Figure A3.5B.27 Test 3/5 (B) Marple M4 Metals Analysis Distribution, mg

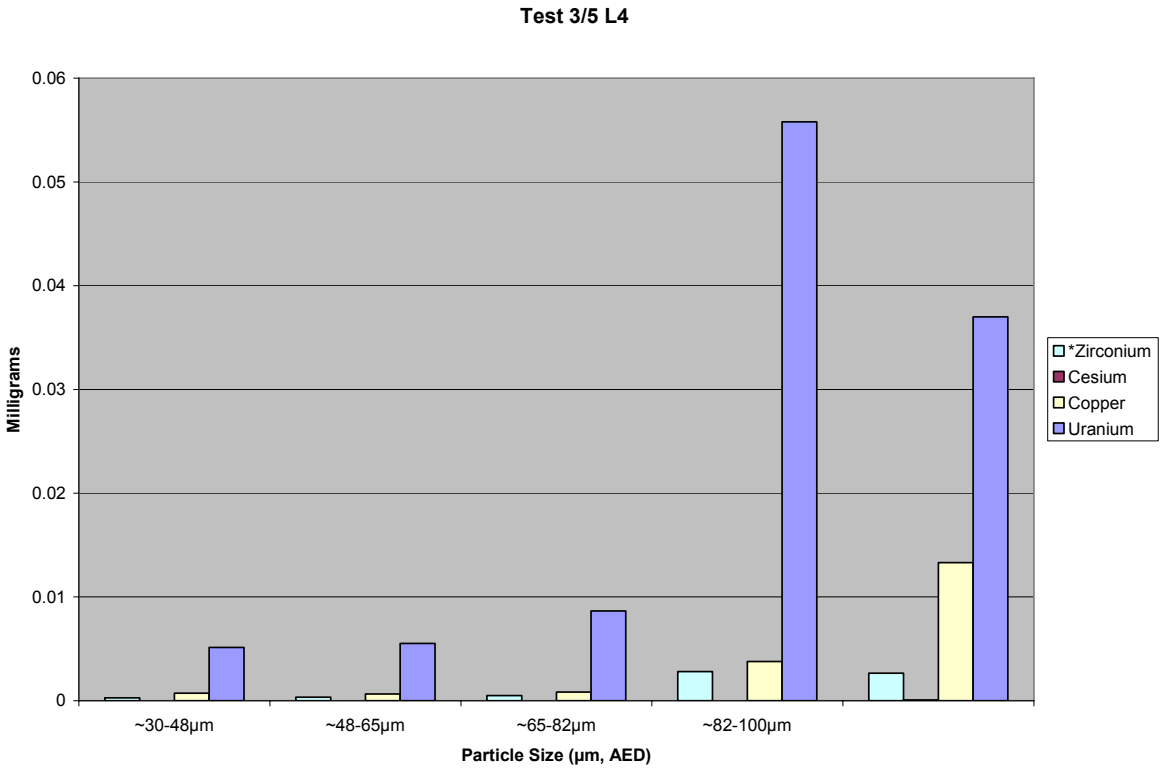


Figure A3.5B.28 Test 3/5 (B) LPS L4 Metals Analysis Distribution, mg

A.3.1C Test 3/1 (C) Analyses and Results

Particulates from the Phase 3 DUO_2 test 3/1 (C) were sampled using four independent Marple impactor and Large Particle Separator systems. In addition, multiple separate impact particle debris samples were collected by a HEPA vacuum system and a pre-separator paper liner (collection bag). Chemical analyses for these particulate samples, including depleted uranium and fission product dopants are not yet available for this report.

Gravimetric and Debris Analyses: Graphs of gravimetric particle size distributions from the four 3/1 (C) Marple impactors, plus the mass concentrations, are presented in Figures A3.1C.29 to Figure A3.1C.33.

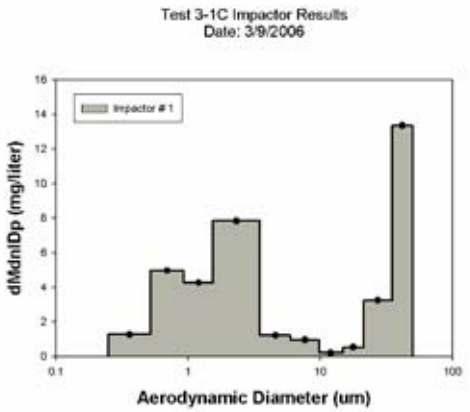


Figure A3.1C.29 Test 3/1 (C) Marple #1 Size Distribution

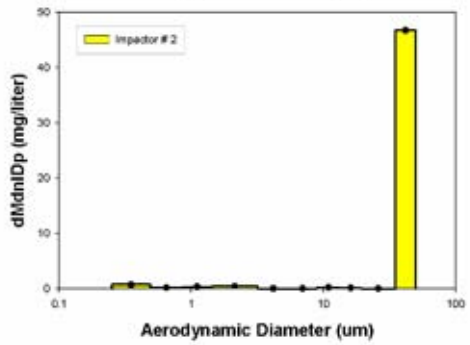


Figure A3.1C.30 Test 3/1 (C) Marple #2 Size Distribution

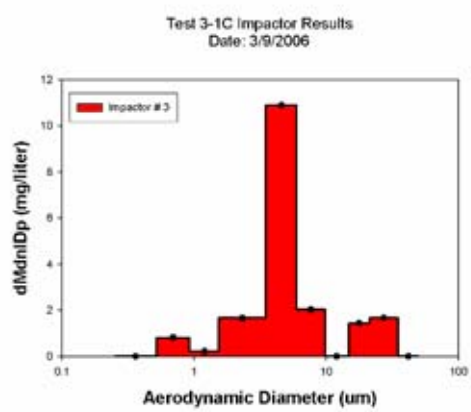


Figure A3.1C.31 Test 3/1 (C) Marple #3 Size Distribution

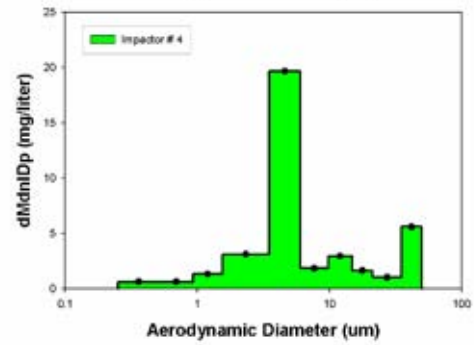


Figure A3.1C.32 Test 3/1 (C) Marple #4 Size Distribution

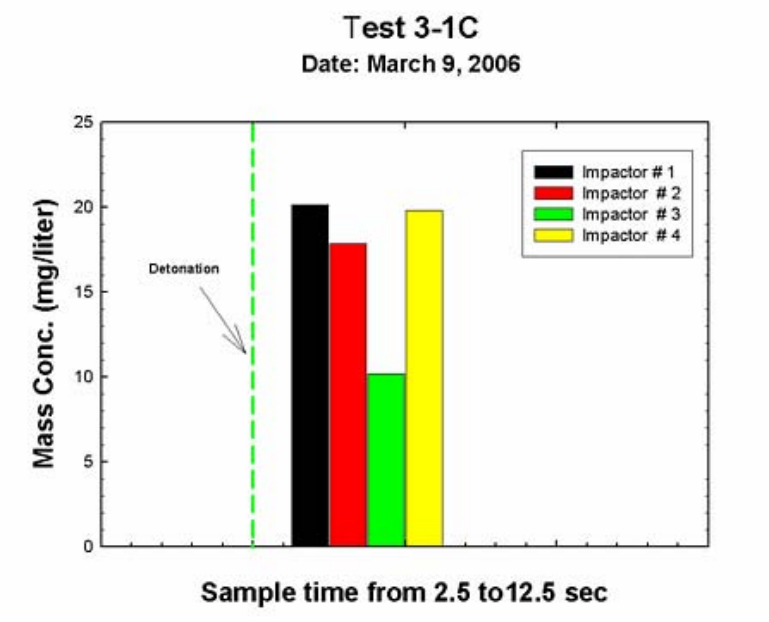


Figure A3.1C.33 Test 3/1 (C) Marple Impactor Mass Concentration Data

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