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Global Nuclear Energy Partnership Fuels Transient Testing at the Sandia National Laboratories Nuclear Facilities: Planning and Facility Infrastructure Options

Edward J. Parma, Milton E. Vernon, Steven A. Wright, Curtis D. Peters, Veena Tikare, Paul S. Pickard, John E. Kelly, Heather J. MacLean

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Abstract

The Global Nuclear Energy Partnership fuels development program is currently developing metallic, oxide, and nitride fuel forms as candidate fuels for an Advanced Burner Reactor. The Advance Burner Reactor is being designed to fission actinides efficiently, thereby reducing the long-term storage requirements for spent fuel repositories. Small fuel samples are being fabricated and evaluated with different transuranic loadings and with extensive burnup using the Advanced Test Reactor. During the next several years, numerous fuel samples will be fabricated, evaluated, and tested, with the eventual goal of developing a transmuter fuel database that supports the down selection to the most suitable fuel type. To provide a comparative database of safety margins for the range of potential transmuter fuels, this report describes a plan to conduct a set of early transient tests in the Annular Core Research Reactor at Sandia National Laboratories. The Annular Core Research Reactor is uniquely qualified to perform these types of tests because of its wide range of operating capabilities and large dry central cavity which extents through the center of the core. The goal of the fuels testing program is to demonstrate that the design and fabrication processes are of sufficient quality that the fuel will not fail at its design limit - up to a specified burnup, power density, and operating temperature. Transient testing is required to determine the fuel pin failure thresholds and to demonstrate that adequate fuel failure margins exist during the postulated design basis accidents.

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CONTENTS

1 EXECUTIVE SUMMARY

The Global Nuclear Energy Partnership (GNEP) fuels development program is currently developing metallic, oxide, and nitride fuel forms as candidate fuels for an Advanced Burner Reactor (ABR). The ABR is being designed to fission actinides efficiently, thereby reducing the long-term storage requirements for spent fuel repositories. Small fuel samples are being fabricated and evaluated with different transuranic (TRU) loadings and with extensive burnup using the Advanced Test Reactor (ATR). During the next several years, numerous fuel samples will be fabricated, evaluated, and tested, with the eventual goal of developing a transmuter fuel database that supports the down selection to the most suitable fuel type.

To certify the fuel for licensing and to assure nuclear plant safety, the Nuclear Regulatory Commission (NRC) will rely on the modifications and exemptions to 10 CFR Part 50 and Part 52 for Sodium Fast Reactors (SFR) including the ABR. The exemptions and modifications are intended to cover omissions and the possible need to extend the range of hazards associated with the ABR. In general, these regulations require that the transmuter fuel not exceed its performance limits during normal operation and during anticipated and off-normal events (design basis accidents). The goal of the fuels testing program is to demonstrate that the design and fabrication processes are of sufficient quality that the fuel will not fail at its design limit - up to a specified burnup, power density, and operating temperature. Transient testing is required to determine the fuel pin failure thresholds and to demonstrate that adequate fuel failure margins exist during the postulated design basis accidents.

To provide a comparative database of safety margins for the range of transmuter fuels, this report describes a plan to conduct a set of early transient tests in the Annular Core Research Reactor (ACRR) at Sandia National Laboratories (SNL). Transient testing in the ACRR was previously used to support the NRC during the licensing review process for the Clinch River Breeder Reactor. The ACRR is uniquely qualified to perform these types of tests because of its wide range of operating capabilities and large dry central cavity which extents through the center of the core. These early transient tests with fission heating will use GNEP TRU-bearing fuels to obtain phenomenological fuel performance limits data under transient conditions. Energy deposition, deposition rate, and other important parameters, such as fuel melt fraction and fission gas content, TRU content, and temperature profile, will be varied to determine pre-failure fuel extrusion phenomenon, onset of cladding breach, and other phenomena. Because of the early development character of the design concepts for the ABR, it is important that transient testing in the ACRR be conducted in such a way that the performance of TRU fuel be compared to the historical database of conventional fast reactor fuels.

For transient testing to be useful, while the GNEP fuels program is still in the “development” phase, data generated from the tests must be intrinsic fuel properties/phenomena and not dependent on the specific reactor design or configuration. Understanding how the presence of transuranics and fission products in the fuel affects its performance in transient tests, as compared to fuel with no transuranics or burnup, is of vital importance. A number of potential pre-failure and failure mechanisms are important including pre-failure fuel extrusion/motion, mechanisms that affect onset of cladding breach, and initial fuel dispersal potential.

Although much phenomenological behavior and performance characteristics can be determine by performing out-of-pile testing for both fresh and burned fuel, in-pile testing is required using nuclear heating to develop the fuel/clad temperature profile at the design or failure limits of the fuel. Nuclear heating is also required for transient heating conditions that simulate reactor specific transients.

ACRR testing, using simple, straight forward experiments and available fuel rodlets during the next few years, will allow for the performance limits of the fuel forms to be evaluated irrespective of the reactor transient conditions. Later years may focus on transient conditions as the ABR design and safety envelope develops. As a down selection to ABR fuel is made in future years, full fuel pin experiments in the ACRR can be performed. The ACRR central cavity dimensions and neutron flux profile is sufficient to support multiple fuel pins of approximately one meter in length. A sodium cooling loop can be incorporated into the experiment package to maintain the desired cladding temperatures during the transient.

A schedule through FY 2012 and budget projection for FY 2008 and FY 2009 has been proposed that would allow for fresh fuel testing in FY 2009. The schedule and budget are consistent with the scope of work delineated in this report.

This work was performed as part of the GNEP fuels development campaign – work package PSN07RDTF01 - Sandia National Laboratories Fuels Transient Scoping Studies.

2 INTRODUCTION

An integral part of the GNEP program includes the testing of potential fuel candidates for the ABR concept. Idaho National Laboratory (INL) has the lead role in developing the fuel and cladding forms, testing the fuels, and analyzing the results. Los Alamos National Laboratory (LANL) is developing oxide and nitride fuel forms. INL is developing metallic fuel. INL continues to conduct burnup experiments on fuel/clad samples (metals, oxides, and nitrides) at the ATR at INL (Hilton, 2003; Hayes, 2006; MacLean, 2006). The ongoing fuels development program will continue for the next several years as the design of the ABR progresses. One aspect of fuels testing that must be considered is the fuel and cladding behavior under transient conditions expected or hypothesized for the ABR. These transient conditions could be off-normal events, design basis accidents, or beyond design basis accidents. Currently only two reactors exist in the U.S. that can be used to simulate these types of transient conditions: the Annular Core Research Reactor (ACRR) at Sandia National Laboratories (SNL), and the Transient Reactor Test (TREAT) facility at INL. The ACRR is currently operating and available for testing; TREAT is maintained in a standby condition.

2.1 ABR Candidate Fuel Forms

Different types of fuel forms have been proposed and are being tested for the ABR. These include metallic, oxide, and nitride fuels with various loadings of uranium, transuranics, and rare earth elements to simulate the possible loading variations in the ABR. Fuels currently being irradiated at ATR are relatively small in size (Hilton, 2003; Hayes, 2006; MacLean, 2006). Typically, these fuel rodlets are 0.16 to 0.19 inches in diameter and 1.5 to 2.0 inches in height. The volume of the fuel in each rodlet is less than one cubic centimeter. A typical metallic fuel rodlet configuration is shown in Figure 1. This configuration is typical for an ATR irradiation of long duration (10% burnup or more).

Metallic and nitride fuel rodlets maintain a sodium (Na) bond to improve heat transfer between the fuel and the cladding. Oxide fuel rodlets maintain a helium (He) fill gas. Although the loading of the constituent isotopes can vary greatly, the fuels typically contain larger quantities of Pu-239 and/or U-235, with some Pu-240 and/or U-238. Other actinide isotopes include Np-237 and Am-241. Rare earth constituents can include lanthanum (La), praseodymium (Pr), neodymium (Nd), and cerium (Ce). Metallic fuels maintain the balance of the mass with zirconium (Zr), oxides with oxygen (O), and nitrides with nitrogen (N). Since the objective of the fuel development work is to identify the fuel behavior and structural integrity as a function of burnup and loading, a relatively large parameter space is being investigated.

Currently only small fuel rodlets are being fabricated and irradiated in ATR as part of the GNEP fuels development program. This is due to both the nature of the scoping studies and the limited quantity of available materials, especially Am-241. It is expected that these small sample sizes of fuels will continue for the next several years. As the work progresses and a down selection to a final fuel form made, it is expected that more prototypical length fuel pins will be produced and tested.

Four categories of fuel rodlets could potentially be required to be tested at ACRR in the next few years. These include:

- Fresh fuel (unirradiated) without Am-241 loading;
- Fresh fuel with Am-241 loading;
- Irradiated fuel (irradiated in ATR at tens of percent burnup) without Am-241 loading;
- Irradiated fuel with Am-241 loading.

The fresh fuel may consist of U and Pu as a mixed oxide or as a Zr alloy, but contains no minor actinides. This form may be referred to as fresh non-TRU fuel, fresh fuel without minor actinides, or fresh fuel without Am-241.

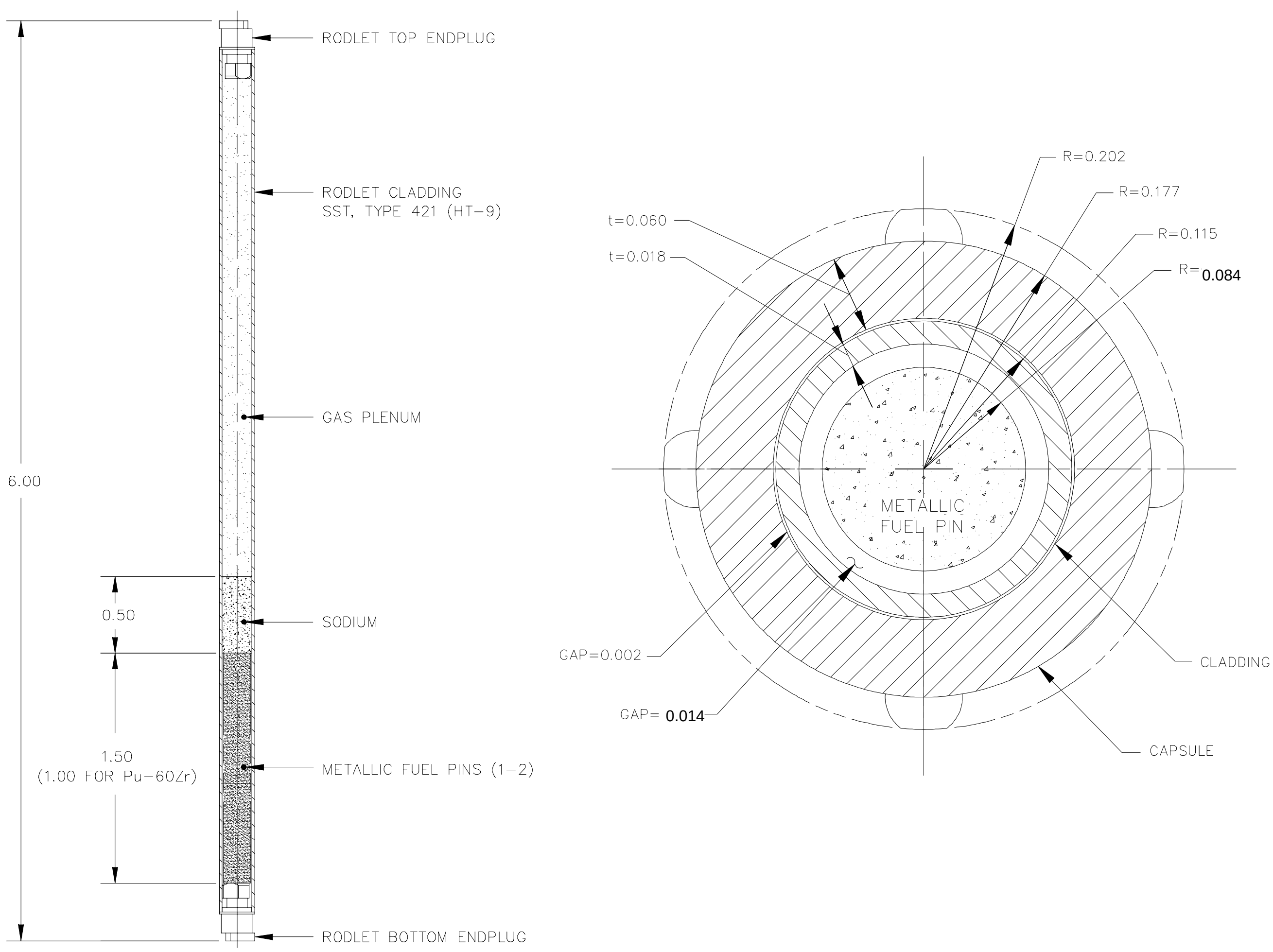

Figure 1. Typical Metallic Fuel Rodlet Dimensions Configured for ATR Irradiation (Units are in Inches).

2.2 *Major Issues for ABR Fuels*

Transient testing will provide data to support the GNEP program in several important ways, including:

1. supporting the down selection of the fuel type which is scheduled to occur in FY 2012,
2. providing key data to guide the advanced fuels modeling and simulations tasks, and
3. directly supporting the licensing case by providing fuel pin failure margin data for the license application to be made to the NRC.

Fortunately, both the U + Pu zirconium alloy metallic and U + Pu oxide fuel forms are highly qualified fuels. However, the new versions of these fuels that contain substantial amounts of minor actinides (5-8 wt% total quantity of Am, Np, and Cm) require testing and certification. A large number of both oxide and metallic fuel pins have been irradiated in EBR-II and FFTF, and a substantial amount of information is known about both. Overall, for the non-TRU fuel, over 100,000 oxide fuel pins and over 10,000 metallic fuel pins have been irradiated. However, only limited testing of the TRU fuel is currently available.

For the ABR design considerations there are two major issues regarding the new transmuter TRU fuels. The first has to do with the down selection of metallic versus oxide based fuel and the second issue focuses on the effects that the minor actinides have on the normal and off-normal fuel behavior. The metallic and oxide based fuel forms are expected to have very different fuel behaviors during off-normal conditions due primarily to their fuel melt temperature relative to sodium boiling and clad melting temperatures. The presence of the minor actinides species in the range of 5-8 wt% is also expected to have an influence on the fuel performance because of the high volatility of Am and the different chemistry associated with these elements. It is known that the presence of Pu affects the behavior of U fuels. Thus there is a strong expectation that the minor actinides will alter the fuel behavior properties, but the character and extent of the influence is unknown. A brief summary and discussion of the major issues that could be addressed with transient tests, or that may affect fuel performance limits for these fuels, is provided below:

- Oxide fuels melt at very high temperatures (~3000 K), which is well above the cladding melt temperature and the sodium boiling temperature. For metallic fuels, the melt temperature is near the boiling temperature of sodium (1200 K) and below the melt temperature of the cladding (1500-1700 K). These opposite thermal physical conditions will likely affect the outcome and phenomenology of fuel behavior accident transients and can be addressed by transient testing for off-normal heating conditions.
- Other issues that affect the thermal conditions within the fuel pin are the fact that metal fuel pins are sodium bonded while oxide pins are filled with helium. This means that the temperature difference between the fuel and cladding for metal fuel is less than for oxide fuel. In addition, because of the high conductivity of the sodium bond and the metal fuel conductivity, the thermal gradients in the metallic fuel are greatly reduced compared to oxide fuels. Again because the transient testing includes both sodium bonded and gas filled pins, these issues can be investigated.
- Both oxide and metal fuels operate at similar fractions of their melt temperature. For metal fuels this means that the maximum normal operating fuel temperature may only be 100-200 K below its melt temperature. For oxide fuels the temperature margins are greater (500-1000K) depending on the power density. The transient fuels test matrix will

treat the fuel temperature and the cladding temperature as independent variables by varying the heating rates of the transients to investigate the anticipated range of fuel and clad temperatures.

- Metal fuel swells significantly more than oxide fuel. Swelling is accommodated by using a low smear density in metallic fuel (75%) compared to oxide fuel (85%). The swelling in metallic fuel occurs relatively rapidly (within 1-2 a% burnup) at which time the fuel is in contact with the cladding. However because of the low smear density, the high relative operating temperature, and the rapid creep rate of the metallic fuel, the strain on the cladding is well within its acceptable design limits. It is unknown as to what extent TRU fuel affects the swelling and cladding strain. Transient testing of metallic and oxide fuels can again address these issues and diagnostics. Using visual or other techniques, it is possible to measure the time dependent strain on the cladding during the transient.
- Swelling of the metallic fuel can result in a substantial axial expansion within the cladding. This effect manifests itself as a significant reduction in reactivity during the first few months of irradiation for a metallic fuel reactor. The axial expansion is dependent on the quantity of Pu in the fuel. This indicates that the quantity of minor actinides in the fuel may also affect the extent of swelling in both the axial and radial directions. Transient testing with full-length fuel pins 0.8-1.2 m in length can be performed in the ACRR reactor. These longer fuel pin tests can address axial fuel swelling and pre-failure extrusion that might be expected during ABR transients. The effect can also be studied with shorter pins, but the location of failure may be different for the longer pins.
- Oxide fuel pins typically release 30% of their fission gas while metallic fuel release 70-80% of its fission gas into the fission gas plenum during normal irradiation. It is not clear how the presence of minor actinides affects the magnitude of fission gas release and its impact on fuel pin failure during off-normal transients. Transient tests with irradiated fuel pins with be performed in the ACRR tests, thus these issues will be addressed.
- Fuel/cladding interactions that are controlled by mechanical pressurization due to swelling, gas pressurization due to fission gas release and perhaps sodium boiling in the bonded region, and chemical interactions at the fuel/clad boundary, all play major roles in the onset of cladding breach. Because the fuel types vary in element composition, it is expected that differences in the magnitude and the nature of the fuel/clad interaction will also vary. These affects can be studied in the ACRR transient testing experiments to determine the mechanisms that drive failure and the conditions at fuel pin failure to determine the margin to failure. Transient tests in the TREAT reactor, for both oxide and metallic fuels, indicate that fuel pin failure occurs at a factor of three to four over nominal power conditions (Lahm, et al., 1993).
- Other issues, such as the location of cladding breach, the impact of the variance of fuel composition, the impact of sodium voiding cause by fuel pin breach, and others, may also play important roles in the fuel performance behavior. To the extent necessary, transient tests in ACRR can be designed to address the specific issue of concern.

This list of issues is provided to illustrate how transient testing can contribute to the database of fuel performance. Other programmatic issues and hazard issues associated with the transmuter fuel must also be considered in order to determine the facility requirements and safety analysis associated with these tests. For example transmuter fuels that contain high quantities of Am and

Cm will pose special handing hazards and may impact fuel performance issues caused by the high vapor pressure of Am.

To support the licensing, modeling and simulation, and safety, it is highly desirable to provide as much information as possible regarding off-normal behavior of TRU-fuels prior to the down-selection process. Much of this information can be obtained from out-of-pile testing of irradiated fuels, but the key issues associated with cladding breach, pre-failure motion/extrusion, and post failure behavior, will require nuclear heating since this is the only method to represent the actual accident conditions. Thus in addition to providing in-pile transient testing that examine phenomenological behavior, some tests might be more science based, investigating issues such as fuel cladding pressurization, strain, and fission gas release/pressurization.

Ultimately, the data gained in the transient tests will be used in three ways. First, it will be used to provide safety margins to help in establishing the licensing case; second, it will support the fuel down-selection process; and third, it will provide experimental data for the advanced fuels modeling and simulation effort.

2.3 Facility Requirements for Testing ABR Candidate Fuels

Support facilities associated with ACRR transient testing are required at SNL. These facilities must provide a location to receive and unload fuel rodlets from INL shipped in an approved Department of Transportation (DOT) container or cask, provision for temporary storage for the fuel rodlets and experiment capsules, glove boxes and associated hardware (shielded and unshielded) to repackage the rodlets into an experiment capsule for testing in ACRR, a facility located close to the ACRR that can accommodate x-radiography, and a set of additional glove boxes (shielded or unshielded) that can be used for limited post-irradiation examination (PIE) and for repackaging and shipment or disposal using an approved DOT container or cask.

ACRR irradiation testing using fresh fuels without Am-241 pose minimal risk to the worker, collocated worker, and public. Only radiological facilities are required to support these types of fuel tests. The dose to the worker is limited by the fission products generated during the ACRR irradiation, which is small. Tests using fuels irradiated to tens of percent burnup in ATR, and fuel types containing Am-241 have the potential for some risk to the worker, collocated worker, and public, and therefore require a more rigorous safety process.

On a per gram basis, Am-241 released in an unmitigated downwind dose calculation has ~100 times the dose equivalence of Pu-239, and hence dominates the hazard categorization required for the support facilities and the safety classification for the containment boundary in the ACRR experiment. For the current fuel rodlets being considered without Am-241, the quantities of Pu-239 and Pu-238 and fission product inventory generated during ATR irradiation are small enough to maintain the support facilities at less than Hazard Category 3, hence only a radiological facility is required. With Am-241 loaded fuels, the support facilities will be required to be Hazard Category 3, but would not exceed the Hazard Category 2 threshold. Later more complex experiments involving longer fuel pins or multiple pins will require Hazard Category 2 support facilities due to the quantities of Am-241 and Pu-238 present.

2.4 Transient Testing Objectives for ACRR

The primary objectives of the transient testing work, proposed here using ACRR, are as follows:

- Identify and develop the transient conditions, configurations, and fuel types to be tested at the ACRR, with input from the GNEP fuels development and modeling team, ABR design team, and ABR safety analysis team;
- Maintain and update currently existing SNL facility infrastructure to perform transient fuels testing at the ACRR using a wide variety of fuel forms and burnup conditions consistent with the GNEP fuels testing program;
- Maintain and update SNL facility infrastructure to receive and store the fuel rodlets from INL, repackage into the appropriate experiment capsule, repackage the fuel rodlets after transient testing, and transport back to INL or other site for disposition or examination;
- Develop test capsules and diagnostic in-situ instrumentation to meet the configuration, testing, and safety requirements for performing irradiation testing in ACRR;
- Perform transient testing in the ACRR;
- Develop post-irradiation diagnostic instrumentation commensurate with the program's needs, including x-radiography and tomography;
- Pursue the development of a post-irradiation-examination (PIE) facility to remove and examine fuel after irradiation in the ACRR – depending on the program's needs. Some limited form of PIE capability will be needed to deal with unforeseen issues that may occur with the fuel testing capsules, and to remove the fuel or otherwise prepare it for shipping to another DOE facility (LANL, or INL) for additional PIE;
- Pursue the further development of the facility infrastructure, to allow for future advanced testing of GNEP and other fuels at the ACRR, including larger, prototypical fuel pin sizes, multiple pin geometries, and coolant types and conditions.

2.5 Purpose of this Document

The purpose of this document is to identify and justify proposed transient experiments in the ACRR and their relevance to the fuels development program; identify the current and potential future facility and infrastructure needs at the SNL nuclear facilities; and develop a draft schedule and funding profile for the next several years. This document is preliminary, in that, since the GNEP program is in its infancy, all of the conditions and needs of the program with regard to transient fuel testing are still uncertain. It is expected that as the program evolves, the need for transient testing of both single rodlets, and more prototypical fuel geometries and configurations will be envisioned and testing of more complicated experiments will be required through the final design stages of the ABR. We propose an evolutionary program which will allow less complicated experiments to be performed in the near term, with more complicated follow-on experiments in the out years. The transient test team, made up of experimenters from SNL, INL, and other labs would work closely with the fuels development team and the other GNEP program groups to make certain the programmatic needs are fulfilled using the ACRR and facility support infrastructure.

3 PROPOSED ACRR EXPERIMENTS FOR GNEP FUELS TESTING

The ACRR has been used extensively in the past to perform nuclear heating tests on power reactor fuels (both intact and degraded core geometries) and space reactor fuels. Many of these test campaigns were international collaborations or NRC supported. Fuel failure phenomenological tests, margin-to-failure tests, fuel/clad interactions, and equation-of-state tests are typical experiments that can be conducted in the ACRR to observe specific fuel behavior phenomena. Visual real-time images and/or other diagnostics, such as pressure, temperature, expansion, gas collection, etc., can be used along with both destructive and non-destructive PIE, to assess the condition and behavior of the fuel during and after the experiment. The ACRR can perform transient or steady-state heating to simulate specific reactor conditions of interest.

For the GNEP fuels testing program, several types of experiments have been identified that will have near-term relevance on the performance and safety margin of the fuel. Comparative experiments on the fuel types, loadings, and burnup are necessary to evaluate the fuel candidates and allow for a down selection based on the results. It is much too early in the ABR design to identify specific accident and transient conditions that that could be simulated in the ACRR. Therefore this document will focus on near-term experiments that will allow for non-reactor specific conditions to be simulated that could have a significant impact on the fuel down selection for the ABR.

Near-term transient testing of developmental TRU fuels will investigate fuel behavior at, or near, anticipated operating margins and allow for comparison of fuel forms and their variations under more challenging conditions than can be achieved during steady-state irradiation. Transient testing in ACRR will complement on-going and future steady-state irradiation experiments in ATR and non-U.S. fast reactors.

3.1 ACRR Performance Potential

The ACRR reactor will be described in more detail in Section 5.1. Figure 2 shows an MCNP neutronics model of the ACRR with a single fuel rodlet at the center of the nine-inch dry cavity. MCNP calculations were performed to determine the coupling factor of the rodlets in the central cavity with no additional moderating material. The coupling factor is determined by calculating the number of fissions in the rodlet compared to the reactor. For a selected sample of rodlet fuels, the coupling factor was consistently found to be ~11 J/cm per MJ of reactor (ACRR) energy with no additional moderation in the central cavity. At an ACRR steady-state power level of 2 MW, the rodlet power would be ~22 W/cm. This is low compared to the 385 W/cm peak linear power and 440 W/cm linear power limit reported in the ABR preconceptual design report (Chang, et al., 2006). However the ACRR is capable of operating in a transient mode and pulse mode, allowing the power level to far exceed 2 MW for short periods of time. The transient/pulse elements can either be programmed to add reactivity at a prescribed rate, or pneumatically ejected causing a reactor pulse. For these operating conditions the reactor is reactivity limited to ~$4.25 of excess maintaining a safe operating condition. The reactivity limit also limits the amount of total energy deposited in the core to ~300 to ~350 MJ. In the programmed transient rod withdrawal mode, a rodlet or full length fuel pin (see Section 3.1.2) can be operated at a high linear power level until the reactor reactivity ($4.25) is consumed by the reactor heat up and associated negative reactivity feedback. Using 350 MJ as the limit, a constant linear power level of 350 W/cm could be maintained for ~11 seconds, 1000 W/cm ~4 seconds, 2000 W/cm ~2 seconds, or 4000 W/cm ~1 second.

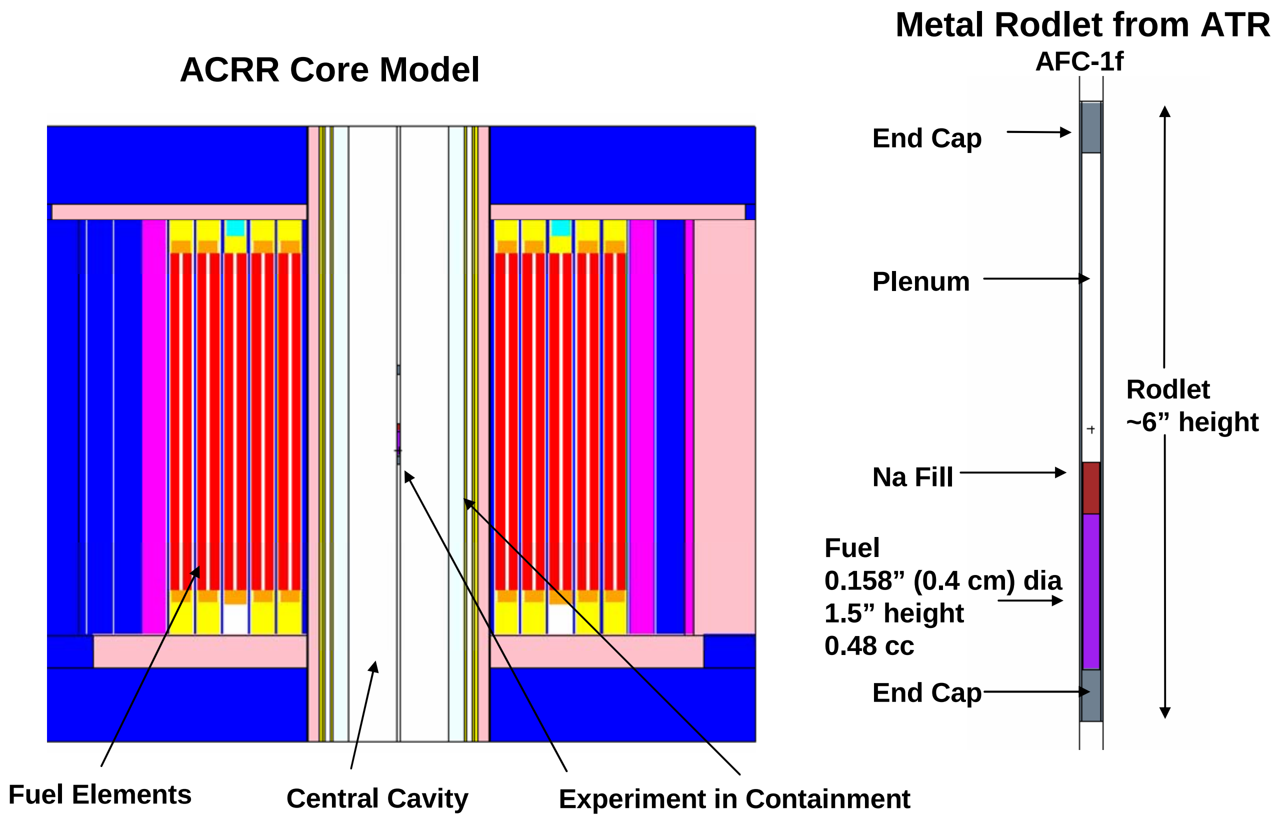

Figure 2. Fuel Rodlet Configured in ACRR Central Cavity.

Reactivity ramp addition experiments can also be performed using the programmed transient rod withdrawal mode. Reactivity rates of any magnitude can be achieved and can be changed continuously during the transient. Rates of \$0.03/s, \$0.50/s, and \$3.00/s, reported in Weber et al. (1981) for fuels testing performance at TREAT, can be attained with the same total energy deposition. Compared to TREAT, ACRR maintains the similar performance capabilities, with the added advantage of a large diameter nine-inch central cavity. The ACRR is an epithermal reactor, which also allows for thermal neutron flux enhancement and a larger coupling factor using moderating material, or for an epithermal/fast flux within the cavity using thermal neutron absorbers. The coupling factor can be increased by approximately a factor of five using neutron moderating materials.

Figure 3 shows a programmed transient ACRR operation performed in September 2007, which could be similar to that desired for a sodium-cooled pin experiment. For this case, the transient mode programmer was configured to operate at a constant power level of ~18 MW for 1.5 seconds, followed by a linear power ramp to ~60 MW in 3 seconds. After 60 MW was reached, the position of the transient rods was held constant, allowing for the core to heat up and shut down the reactor. A total energy of 210 MJ was deposited in the ACRR over the 8 second transient.

The ACRR transient mode operation is versatile and allows for power levels in the tens of megawatt range to be achieved for second time intervals. This mode allows for constant power, power ramps, and pulses to be performed, depending on the desired profile of interest.

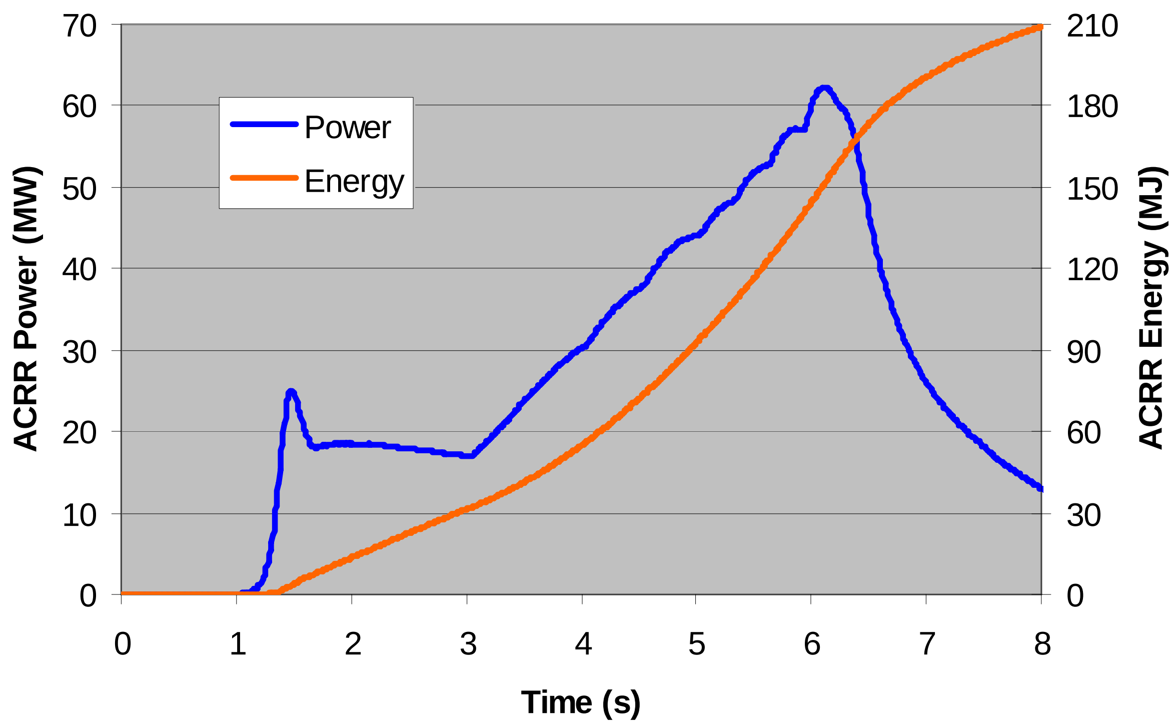

Figure 3. ACRR Transient Mode Operation – Constant Power With Ramp Increase.

3.2 Fuel Testing Options

Three specific types of ACRR experiments have been identified that would have a major impact on fuel selection and on the development of the fuel performance database to support licensing for the ABR. The first type experiment is a capsule with the potential for making visual observations of cladding breach and pre-failure fuel motion/extrusion phenomena. The second test configuration consists of a sodium cooled loop with full length fuel pins (single pin or multi pin). The third configuration consists of a set of special test capsule configurations that can be performed to support more science based testing rather than phenomenological testing. The science based tests could be used to measure the equation of state (EOS - pressure versus enthalpy) for fresh, fresh-TRU, and irradiated fuel pins similar to past EOS experiments performed on UO_2 and MOX fuel pins in the ACRR. Other tests could also be performed, such as tests that directly measure the internal pressure in a fuel pin during design basis accident transients.

Figures 4 and 5 illustrate the types of capsules that might be used to for visualizing the fuel performance behavior. Figure 4 shows a capsule with double containment that was used to observe the phenomenological behavior of fuel pin failure for MOX fuels in the ACRR at SNL. Partially mirrored surfaces, lighting, and quartz windows were used to allow for high-speed cinematography of the fuel disruption. For the rodlet fuel pin samples that contain only 1.5" of fissile length, more than one sample can be arranged in the capsule as illustrated in Figure 5. This visual arrangement of multiple fuel samples has been used numerous times in the ACRR.

Figure 4 shows a double-containment experiment capsule used in the central cavity for previous fuels transient testing. Double containment is anticipated for the rodlet tests containing TRU materials (see Section 4.3). Experiments can be conducted with a single fuel rodlet, or with multiple rodlets tested simultaneously. Figure 5 shows a configuration where multiple rodlets would be tested at different axial locations. Shown in the figure are primary containment boundaries around each fuel rodlet and a secondary containment boundary encapsulating the primary vessels. By arranging the rodlets at different axial locations within the core, the neutron flux can be varied within the same transient test. Rodlets could also be grouped at the same axial location to allow them to be subjected to the same neutron flux and transient conditions.

3.2.1 Visual Imaging Test Capsules

Capsules that provide for visualization of the fuel rodlet offer a number of advantages over other types of testing. First they provide a direct qualitative observation of the fuel behavior and clearly identify the timing and quality of fuel melting, clad melting, release of aerosols, fuel breakup, fuel sputtering, cladding breach and general nature of initial fuel motion. All of this information is available within minutes or hours after the test. This approach allows for the potential performance of a large number of tests. It also allows for advanced diagnostic instrumentation, including single and two color pyrometetry, spectroscopy, directly lit, back lit, and self illumination, Raman spectroscopy, and other forms of laser probing such as dilatometry and interferometry. Except for interferometry and dilatometry, all of these forms of visual instrumentation have been used successfully in the ACRR.

It is expected that the first set of tests would use static capsules of this design coupled with high speed cinematography using modern day, advanced, high-speed digital cameras located on the reactor floor. Telescopes, lenses, and mirrors would be used to peer down the central cavity into the test capsule. An in-situ heating system could be used to preheat the fuel rodlet and cladding to the desired starting temperature, which could be between 500°C and 900°C depending on the transient and the heat loss expected in the test. Both direct electric heating and resistance wires could be used. Rapid power transients would require more preheating of the cladding to assure that it was near its desired operating temperature, while slower transients would require less preheating.

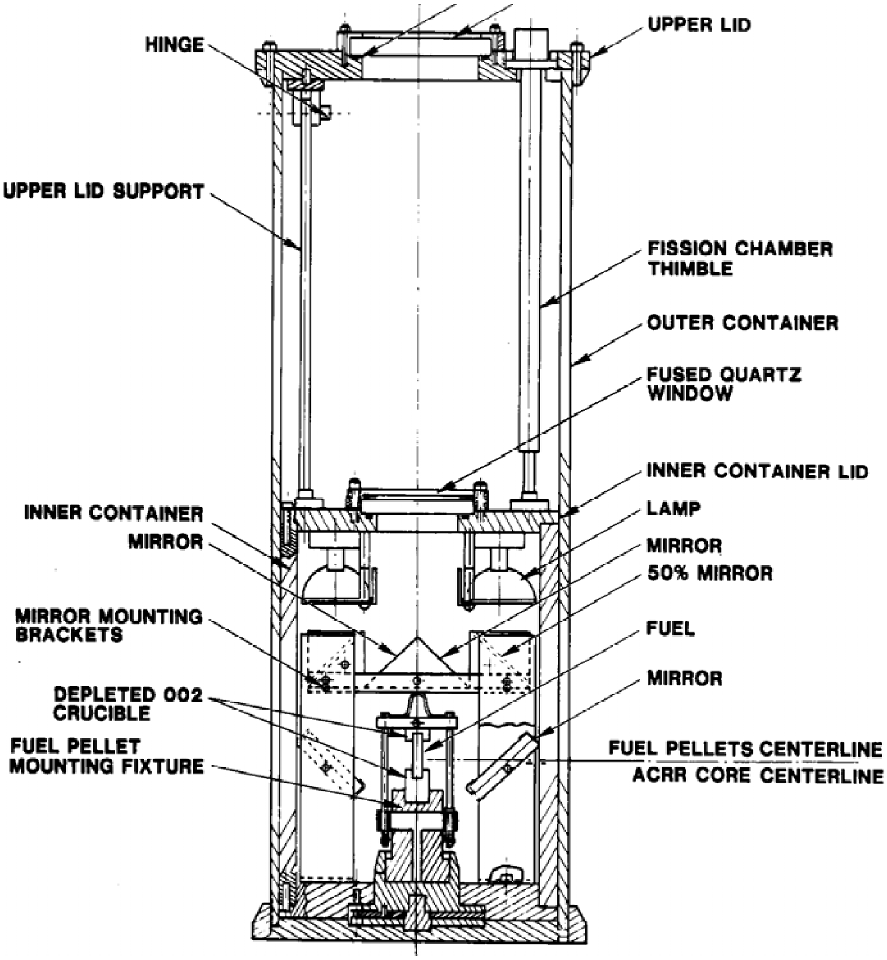

Figure 4. Double Containment Experiment Capsule With Visualization of the Fuel Rodlet.

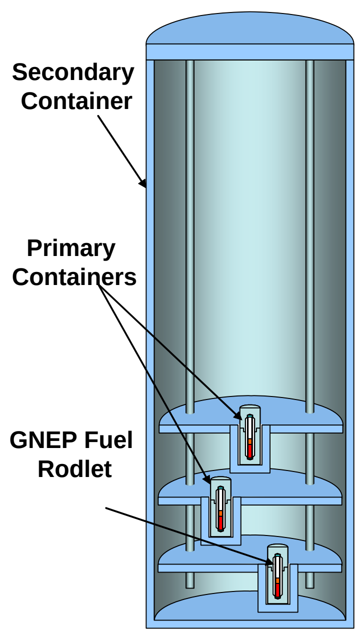

Figure 5. Double Containment Experiment Showing Axially Staggered Rodlets.

3.2.1.1 Cladding Breach Testing

Cladding breach testing can be performed for metallic, oxide, and nitride fuel forms. In order to study cladding breach, the rodlets could be used as irradiated in the ATR, without further modifications. For cladding breach tests, rodlets would be preheated to a moderate temperature and the reactor power transient programmed to heat the fuel over a period of 4-8 seconds (or longer if desired) to fuel melt (through 90% melt fractions). The cladding temperature in the fuel region would be heated to a pre-specified temperature below cladding melt. Figures 6 and 7 notionally illustrate a power transient temperature transient for one of these types of tests. For a multi-rodlet test, breach of cladding would occur in the peak power density rodlet, with no breach expected in the lower power density rodlets. After the test, x-radiography could be used to observe the extent of pre-failure motion in the un-breached rodlets.

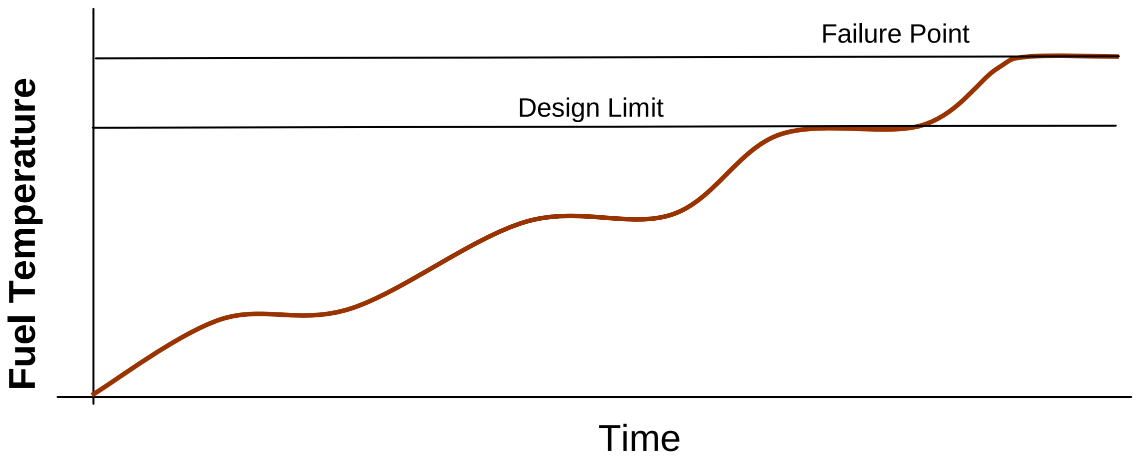

Figure 6. Possible Transient Test to Determine the Margin to Fuel Failure.

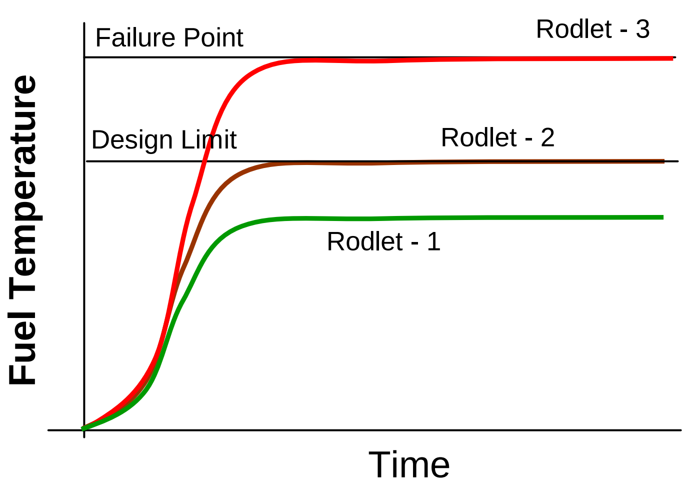

Figure 7. Possible Transient Test to Determine Margin to Fuel Failure With Axially Staggered Rodlets.

3.2.1.2 *Pre-failure fuel motion/extrusion Testing*

Pre-failure fuel motion testing is more applicable for metallic fuels. In order to study pre-failure fuel motion, the rodlets would need to be modified by first cutting off the upper plenum and Na column in a shielded glovebox. A fused quartz tube would be placed around the remaining rodlet to allow for high-speed observations of pre-failure fuel extrusion into the quartz tube during a design basis power transient simulation. It is expected that during the transient, the cladding would remain cool and the fuel would expand resulting in axial expansion/extrusion into the upper quartz "cladding". This visualization would allow for the quantification of the amount of extrusion that occurs as a function of time and temperature for various types of fuels, including fresh, irradiated, TRU loading, and metal versus oxide.

3.2.1.3 *Potential Test Matrix*

Based on the previous discussion, a reasonable starting test matrix might consist of tests that study both the conditions that cause cladding breach and the extent of pre-failure fuel motion/extrusion using the rodlets that are currently being fabricated and tested in ATR. The initial test matrix shown in Table 1 is provided to initiate discussion. The tests assume that capsules similar to those illustrated in Figure 4 and 5 would be used to irradiate a variety of fuel rodlet types with visualization methods to include metallic and oxide fuel pins with and without minor actinides in both the fresh and irradiated conditions. The power transients would notionally consist of power ramps that increased in power from nominal power (~300 W/cm of length) to elevated powers 3-4 times nominal or more over different time periods (4-20 seconds). The goal would be to initiate fuel cladding breach or failure at different power conditions, where the fuel and cladding temperature difference might vary from 400°C to 200°C to 100°C. Other independent variables would consist of irradiated fuels with varying burnup.

Table 1. Potential test matrix for a series of capsule visualization tests to study cladding breach and pre-failure fuel motion/extrusion.

Metallic and Oxide Fuel Fuel Loading Type	High Power Ramp 400°C ΔT	Medium Power Ramp 200°C ΔT	Low Power Ramp 100°C ΔT
Fresh Fuel – No Minor Actinide Loading	X	X	X
Fresh Fuel – With Minor Actinide Loading	X	X	X
Irradiated Fuel – No Minor Actinide Loading	X	X	X
Irradiated Fuel – With Minor Actinide Loading	X	X	X

If this test matrix were performed, then over 24 fuel rodlets (more if multiple rodlets were used) could be tested to these transient conditions for both the metallic and oxide fuel forms in a time frame to support the fuels down select ion (by 2012) and to guide computer modeling. Both the fuel performance limits and behavior for cladding breach as well as pre-failure fuel extrusion would be determined. Clearly a test matrix of this type will likely be modified as the tests progress, and as more experimental data is collected about the fuel performance limits and the phenomenological behavior.

3.2.2 Full Length Pin Testing in Sodium Loop Test Capsules

Sodium loop capsules of various types can be used to test fuel behavior in more prototypic transient test simulations. Figure 8 shows a notional concept of two types of sodium loops that could be used within the ACRR nine-inch dry central cavity. The left loop uses an annular linear induction pump (ALIP) to force circulate the molten sodium through the experiment package cooling the fuel pin cladding to the prototypical conditions. The right loop shows a more traditional loop-test similar to that used in TREAT. Fuel pin disruption tests using fresh UO_2 and UC have been performed in stagnant sodium tests in the past at the ACRR facility. These tests are clearly within the capability of the reactor but would require more effort to perform, due to the large amount of fuel and the intermixing of sodium with the irradiated TRU fuel. Disposal issues are also a concern. These types of tests would most likely be non-visual. However, visual testing could be performed if molten salt were used as the coolant and if the loop boundary were made of fused quartz.

For these types of tests, the specific cooling capabilities of the loop would be determined by the experiment requirements. Using liquid sodium, prototypic conditions that would simulate the ABR can be attained by using similar flow rates, pressure drops, and flow channel dimensions. If required, heat exchangers and heaters can be added to the cooling loop configurations to maintain prototypical inlet coolant temperatures. No heat transfer calculations have been performed to-date for a conceptual design of this experiment. However, the heat transfer mechanisms for this experiment are straightforward, and the unit can be tested out-of-pile prior to use to confirm its functionality.

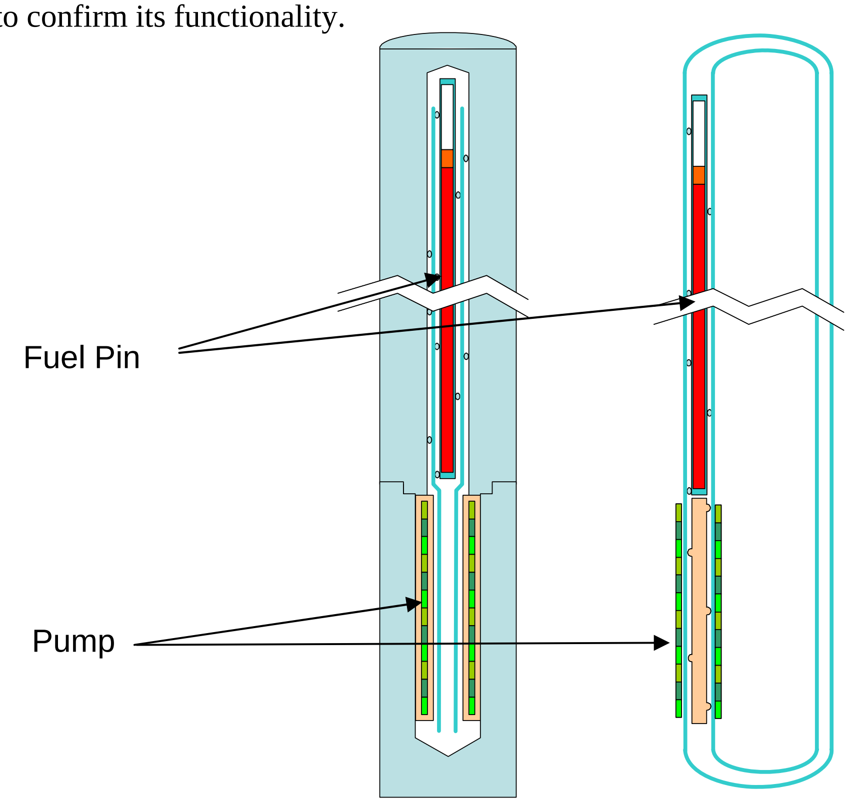

Figure 8. Full Fuel Pin or Bundle Testing Using a Sodium Cooling Loop. Left Loop Shows an Integrated Experiment, Right Loop Shows a More Traditional Loop Arrangement.

Figure 9 shows an MCNP model of an 80-cm length fuel pin located in the central cavity of ACRR. Although the ACRR core height is only ~52 cm, the relatively large central dry cavity allows for a significantly large neutron flux to exist beyond the fueled region of the core. Figure 10 shows the normalized fission density in an 80-cm length fuel pin within the central cavity, calculated using MCNP. The fission density for a variety of conditions and reflector materials within the cavity were analyzed. The "normal-blue" curve shows the results with no additional neutron moderation or filters within the cavity. This condition results in a cosine-type shape fission distribution with a peak-to-average value of ~1.4. Neutron moderators or filters can be added to change the energy spectrum or the axial flux shape within the cavity. The "shaped poly inserts-purple" curve has some polyethylene in the outer regions of the cavity, allowing for a relatively flat fission distribution axially through the fuel pin. Other variations in moderation and filtering can be used to achieve the desired fission distribution. The distribution at the upper end of the core (right side of Figure 9) is less due to the control rod positioning within the core. Again slight modifications in the thickness of the moderator shims can be used to trim the power profile to the specified conditions.

The dry central cavity extends several feet below the ACRR core and would allow for a liquid sodium loop, described above, to be tested. Testing several fuel pins in a bundle arrangement is also conceivable. The limitation on the ACRR is the size of the central cavity (9 in.) and the total energy deposition in a transient (300 to 350 MJ).

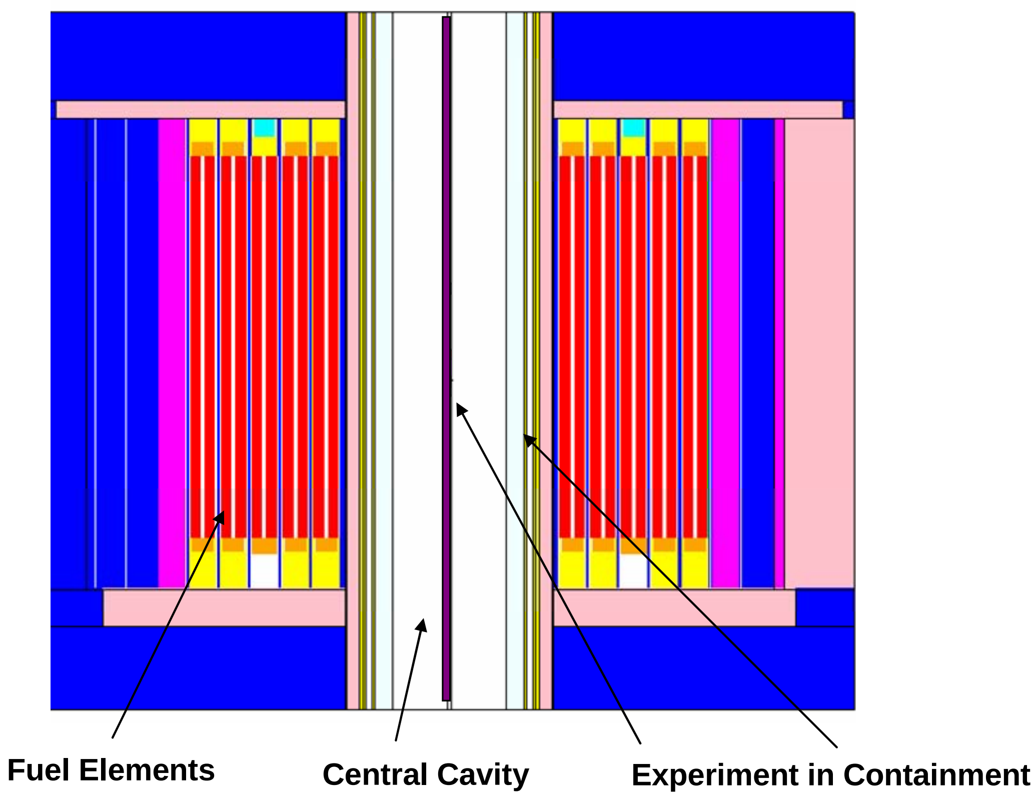

Figure 9. MCNP Model of a Full Length Fuel Pin in the ACRR Central Cavity.

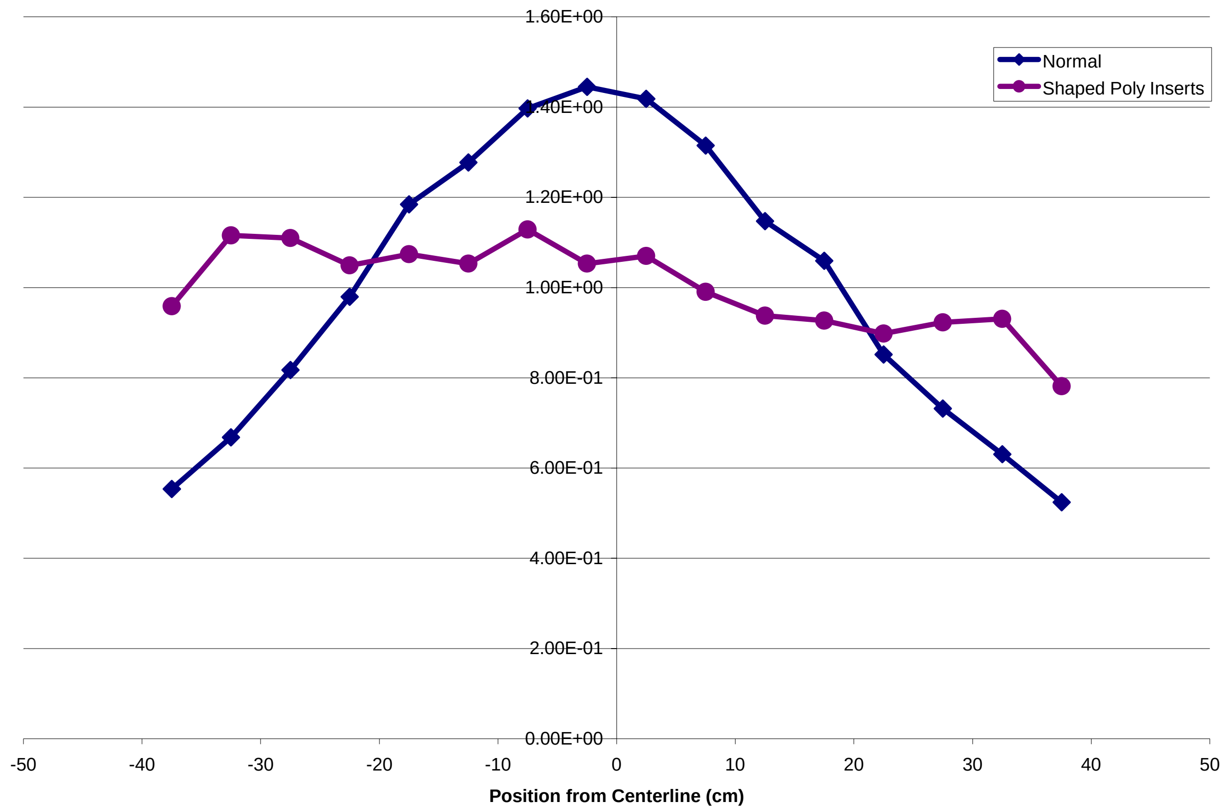

Figure 10. Normalized Axial Fission Profile for an 80-cm Long Fuel Pin in the ACRR Central Cavity. The Dark Blue Line Represents the Fission Density Without Additional Moderation. The Purple Line Represents the Fission Density With Polyethylene at the Ends to Enhance the Neutron Flux.

3.2.3 Science Based Test Capsules

A variety of science based tests and test capsules can be considered including EOS measurements and fission gas plenum pressurization during transients. These tests are notionally illustrated in Figure 11. These types of test capsules would be designed to specifically measure a phenomenon, for example, the internal pressure of the fission gas plenum during a design basis transient. Tests capsules of this type have been used to measure the EOS of UO_2 and MOX fresh and irradiated fuel in the past. For these tests, a 0.5 gram sample of fuel was subjected to a rapid power transient with sufficient energy to vaporize the fuel. The expanding fuel would condense on the surface of a piston that pressed against a pressure transducer. The measured vapor pressure was therefore measured as a function of enthalpy deposited during the ACRR transient. These measurements may be important for use in reactivity driven accident modeling efforts, and to assess the thermophysical differences between irradiated and fresh fuel. In general these types of tests support model development, and are focused at quantitatively measuring some specific phenomenon.

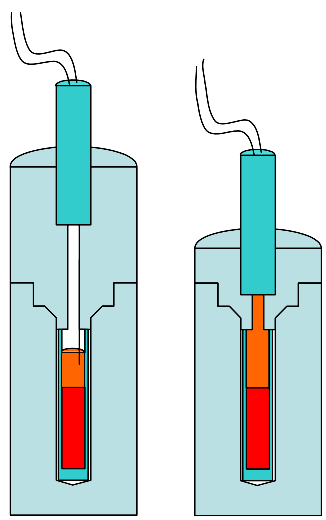

Figure 11. Fission Gas Pressurization (left) and EOS (right) Test Capsules.

3.3 *Proposed ACRR Experiment Schedule*

The time constraints for performing fuels transient testing at the ACRR are the availability of the fuel forms and the budget. A preliminary detailed schedule and budget profile are presented in Section 6 of this report. Figure 12 shows a high-level proposed schedule for performing the ACRR testing using the current fuel availability dates. Fresh metallic fuel will begin to be available in FY 2008 and oxide fuel in FY 2009. Fuel irradiated in ATR would be available starting in FY 2010. The current plan is to have fresh fuel (without Am-241 loading) ACRR testing start at the beginning of FY 2009. Testing with Am-241 loaded fresh fuel would follow later in FY 2009. Availability of low burnup fuels would not be until FY 2010 and high burnup fuels in FY 2011. Follow-on testing with more prototypical pins would be dependant on the fuel availability, which has not yet been planned by the fuels test program.

It is currently unknown as to how many tests would be required for each fuel form. Once the approvals have been established for ACRR testing for a given experiment type, the testing could proceed in a relatively efficient and sequential manner. The constraint would be the fuel availability and the needs of the fuels development program.

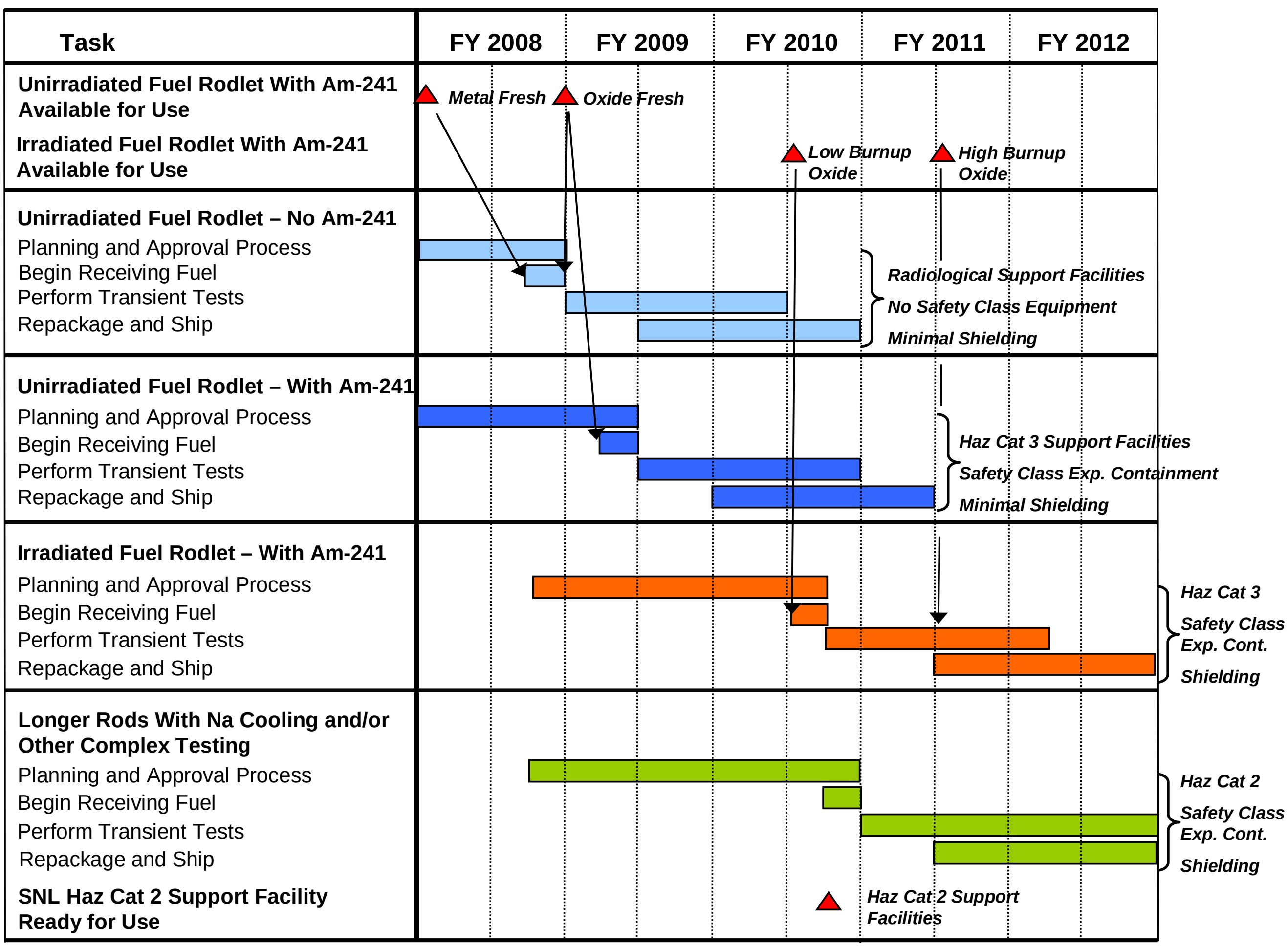

Figure 12. Proposed High-Level Schedule for ACRR Testing of GNEP Fuels.

4 EXPERIMENT CAMPAIGN REQUIREMENTS

Fuel samples are currently being fabricated at INL and LANL, and are irradiated at the ATR to the desired burnup conditions. Once the fuel forms are available, they can be shipped to SNL for testing at the ACRR. However, before testing at the ACRR can begin, a significant planning and approval effort must be coordinated to ensure the fuel can be accepted, tested, and sent back to the source. The process for testing at the SNL Technical Area-V (TA-V) Nuclear Facilities involves having the right support facilities available and approvals established for accepting, handling, and testing the fuel. This section describes the experiment campaign requirements that are currently envisioned for fuel testing in the next several years at TA-V. These requirements are tentative and have been established using the currents scope for early fuels testing.

4.1 Flow Process for Fuels Testing

The following flow diagram and bullet lists show the flow process for testing the GNEP fuels at the ACRR. Although post irradiation examination (PIE) is included in this flow diagram, PIE at TA-V would be limited to non-destructive examination (NDE) due to the current SNL hot cell availability.

receive fuel from INL or other → load experiment capsule → conduct test at ACRR → conduct PIE (NDE) → load shipping cask → repackage fuel for shipping → return fuel to INL or other for PIE and disposition

- Fuel receipt, unloading DOT cask, storage at support facility
- Fuel movement to experiment capsule loading area
- Fuel loading into experiment capsule
- Experiment capsule transfer to ACRR
- Conduct ACRR experiment
- Experiment capsule storage at ACRR post-test
- Experiment capsule movement to PIE (NDE) area
- PIE (NDE) testing
- Fuel repackaging for shipment
- Fuel movement to shipping area
- Load DOT cask, ship

The fuel must first be shipped in a DOT or other approved container from the source to TA-V. The container may be a Type A container for fresh fuel and a Type B container for irradiated fuel. The shipping container may be different from that currently used at ATR and the INL Hot Cell facility since only small rodlets are envisioned to require shipment in the early testing phase. There has been some discussion as to whether fuel rodlets or the complete experiment capsule is shipped to SNL. For the current planning effort, it is assumed that SNL would repackage rodlets into the experiment capsule in TA-V. For simple experiments, where the rodlet is used as is, this would be relatively straight forward. For more complex experiments where the rodlet cladding must be modified to accept a gas manifold or pressure transducer, this could be a more complex operation requiring a glovebox. The shipping container must be manageable at the TA-V support facility accepting the package, and the support facility must have the correct hazard categorization, approval authority, personnel training, and procedures for operating the container and handling its contents. It is assumed for the rodlet tests that at least a Hazard Category 3 facility will be required to accept and unload the shipping container. Hazard categorization and TA-V facilities are discussed in the following sections.

Repackaging the rodlet into the experiment capsule, primary containment, and secondary containment, may be performed at the same facility accepting the shipping container, or a different facility, depending on the authorization basis of the facility and the hardware requirements. For irradiated fuels or fuels loaded with Am-241, shielding will need to be incorporated into the repackaging effort. For experiments where the rodlet cladding is required to be breached, a glovebox, or shielded glovebox, will be required for repackaging.

Transfer of the rodlet or experiment package to another facility or to the ACRR will require a shielded, on-site transfer container. Once at the ACRR facility, the experiment package can be remotely handled and placed in a storage area or in the ACRR central cavity.

With the experiment package loaded in the ACRR central cavity, the diagnostic and/or viewing equipment will be installed and the experiment performed. After some time period for fission product and activation product decay (tens of hours) the package will be removed from the cavity and stored in a shielded area for further decay. The current plans are to potentially only perform NDE testing on the experiment package or fuel rodlet. Destructive PIE is not planned to be performed at SNL unless deemed necessary by the fuels development program. The experiment package will either be unloaded at the ACRR facility or be moved to a different facility for repackaging, depending on the nature of the experiment and the hardware requirements.

At some point in time following the ACRR experiment, the rodlet or primary container with the rodlet inside, will be repacked into a shipping container for shipment back to the source or to another laboratory for further PIE.

4.2 Facility Requirements

As noted earlier, the support facilities at TA-V must have the right equipment for handling the shipping containers, storing the material, shielding and equipment for repackaging, and authorization basis for operating the facility with the proposed fuel forms.

One important requirement is to determine the hazard category needed for the facility to handle the fuel. Hazard categorization is determined using the DOE Standard 1027. A facility that has material quantities less than the Hazard Category 3 threshold is considered a radiological facility. A Hazard Category 3 facility requires an authorization basis (AB) approved by DOE, including a Documented Safety Analysis (DSA) and Technical Safety Requirements (TSRs). Exceeding the Hazard Category 2 threshold requires a more rigorous AB. Research reactor facilities, like the ACRR, are Hazard Category 2 facilities.

Table 2 shows threshold quantities from DOE-1027 for selected isotopes of interest. Pu-238 and Am-241 are highlighted because they are the isotopes which will exceed the threshold requiring a Hazard Category 3 facility for the GNEP fuel rodlets; Am-241 for the fresh fuel with Am-241 loading, and Pu-238 for the irradiated fuels loaded with Np-237 and Am-241. Note that typically the Hazard Category 2 threshold values are a factor of ~100 larger than the Hazard Category 3 threshold quantities.

Table 2. Hazard Categorization Threshold Quantities for Selected Isotopes.

Isotope	HazCat 2 Threshold (g)	HazCat 3 Threshold (g)
Actinides		
U-233	2.3e4	440
U-234	3.5e4	670
U-235	1.1e8	1.9e6
U-238	7.1e8	1.3e7
Np-237	8.3e4	600
Np-238	3.5	0.005
Pu-238	3.6	0.036
Pu-239	900	8.4
Pu-240	244	2.28
Pu-241	28	0.31
Pu-242	1.5e4	158
Am-241	16	0.15
Cm-242	0.51	0.0097
Cm-245	310	3.0
Fission Products		
Sr-90	160 (2.2e4 Ci)	0.12 (16 Ci)
Ru-106	1.9 (6.5e3 Ci)	0.03 (100 Ci)
Cs-137	1000 (8.9e4Ci)	0.69 (60 Ci)
Ce-144	26 (8.2e4 Ci)	0.031 (100 Ci)
Mixed Fission Products	1000 Ci	--

Table 3 shows typical quantities of materials in a fuel rodlet. Rodlet AFC-1F-1 is a metallic fuel with U-235, U-238, Pu-239, Pu-240, Np-237, and Am-241. This rodlet was chosen for illustrative purposes and may or may not be representative of actual fuel to be tested at ACRR. An ORIGEN-2 calculation was run using a fast spectrum at 10% fissile burnup over a period of one year irradiation to determine, qualitatively, the isotopic inventory of the ATR burned fuel rodlet. Two decay times were considered following the irradiation, 100 days and 1 year. The calculation is again for illustrative purposes and may not be truly representative of burned fuel. The highlighted isotopes, Pu-238 and Am-241, represent the values that approach or exceed the

Hazard Category 3 threshold quantities. However, the quantities are about a factor of 100 from the Hazard Category 2 threshold values.

Table 3. Isotopic Inventories for Rodlet AFC-1F-1.

Isotope	Fresh (g)	10% Burnup 100 day decay (g)	10% Burnup 1 year decay (g)
Actinides			
U-233	--	0.0	0.0
U-234	--	0.0	0.0
U-235	1.16	1.04	1.04
U-238	0.33	0.32	0.32
Np-237	0.10	0.090	0.090
Np-238	--	0.0	0.0
Pu-238	0.001	0.012	0.013
Pu-239	1.04	0.94	0.94
Pu-240	0.21	0.22	0.22
Pu-241	0.006	0.009	0.009
Pu-242	0.004	0.006	0.006
Am-241	0.16	0.14	0.14
Cm-242	--	0.003	0.001
Cm-245	--	0.0	0.0
Fission Products			
Sr-90	--	0.0027 (0.36 Ci)	0.0027 (0.36 Ci)
Ru-106	--	0.0013(4.2 Ci)	0.0008 (2.6 Ci)
Cs-137	--	0.0065 (0.58 Ci)	0.0064 (0.56 Ci)
Ce-144	--	0.0026 (8.4 Ci)	0.0014 (4.4 Ci)
Total Fission Products	--	68 Ci	19 Ci

Assuming this example case would be typical of a fuel rodlet loaded with Am-241, it is obvious that, as a minimum, Hazard Category 3 facilities will be required for Am-241 loaded fuels, and irradiated fuels. Fresh fuels not containing Am-241 and not irradiated will not exceed the Hazard Category 3 threshold and could be handled in a radiological facility. The Hazard Category 2 threshold would not be exceeded, even for many rodlets shipped to SNL. The

Hazard Category 2 threshold could be approached in later years for the full-scale pin experiments that contain significant quantities of Am-241.

In summary, only radiological facilities will be required for fresh fuel rodlets that do not contain Am-241. Hazard Category 3 facilities will be required for handling and storage of a single, or multiple rodlets containing Am-241 and rodlets irradiated in ATR. It is not expected that Hazard Category 2 facilities be required for handling and storage of rodlets. Full-scale pins containing Am-241 may require the use of a Hazard Category 2 facility for handling and storage, but this would not be expected for many years.

4.3 Safety Approval Process

In order to perform fuels testing experiments at TA-V, a safety approval process must be performed to ensure that the worker, collocated worker, public, and environment are protected. This process involves satisfying the requirements imposed by SNL corporate environmental safety and health (ES&H), TA-V nuclear facility requirements, and the DOE requirements. A number of documents must be created, reviewed, and approved prior to performing the test campaigns. Safety review panels at SNL, with DOE oversight, are convened to determine if the experiments can be conducted safely and with minimal risk to the public, collocated worker, worker, and facility.

The following list identifies a general outline of the processes, documents, and approvals that must be completed in order to perform testing at the TA-V nuclear facilities. A significant fraction of the budget for performing tests is devoted to the approval process to ensure that it is completed in a timely and efficient manner.

- Sandia QA (Quality Assurance) Plan
- Sandia NEPA (National Environmental Policy Act) approval
- Sandia PHS (Primary Hazard Screening)
- Safety class containment requirements determination
- Safety basis for support facility activities
- Safety basis for ACRR facility activities
- Support facility DSA review and USQD (Unresolved Safety Question Determination)
- ACRR facility DSA review and USQD for the fuels testing activities
- Experiment Plan approval
- Experiment capsule design, fabrication, assembly, to meet safety class requirements
- Experiment capsule testing to meet safety class requirements
- Sandia pressure safety package
- Experiment procedures – fuel acceptance, experiment loading, transfer, testing, etc.
- Radiological work permits
- Readiness assessments – as deemed necessary by SNL management
- Training of personnel

In addition to SNL process requirements for fuels testing, other processes must be identified that are required for fulfilling the project. These currently include:

- Shipping Container – SARP (Safety Analysis Report for Packaging)
- Training and certifications for operating and handling shipping container

One of the process requirements for testing in the ACRR is to determine the containment requirements for the experiment capsule. If the containment is determined to be safety class equipment, then additional requirements, documentation, and certifications must be performed on the capsule. This may include double containment design, design calculations, design review, material certifications, quality inspections, pressure testing, and leak testing.

In order to determine safety class designation, a downwind dose calculation is performed assuming the entire isotopic inventory in the fuel rodlet, known as the material at risk inventory (MRI), is released with no filtering, plate out, or deposition. If the dose value at 1350 meters exceeds 5 rem then the ACRR DSA requires safety class containment. Table 4 shows the results for the same AFC-1F-1 rodlet example used earlier for demonstration purposes. The downwind dose at 1350 meters is dominated by the Am-241, 14.5 rem, followed by Cm-242, 8.8 rem, and Pu-238, 3.4 rem, for 100 day decay following a 10% burnup in ATR. The value for the Am-241 alone is well above the 5 rem threshold for safety class containment. Therefore, fresh fuels and irradiated fuels containing Am-241 will be required to have safety class containment integrated into the experiment capsule. Fresh fuel and irradiated fuel that does not contain Am-241 may be less than the safety class threshold, but will need to be evaluated on a case-by-case basis.

Table 4. Downwind Dose at 1350 m for MRI of Rodlet AFC-1F-1.

Isotope	10% Burnup 100 day decay (Rem)	100 day decay Percent of Total Dose	10% Burnup 1 year decay (Rem)	1 year decay Percent of Total Dose
Np-237	0.002	--	0.002	--
Pu-238	3.4	11	3.9	16
Pu-239	1.1	4	1.1	5
Pu-240	0.97	3	0.97	4
Pu-241	0.31	1	0.30	1
Am-241	14.5	49	14.5	61
Cm-242	8.8	30	2.9	12
Total - All Actinides	29.2		23.7	
Total - All Fission Products	0.15		0.08	

5 SNL TECHNICAL AREA V NUCLEAR FACILITIES

SNL TA-V maintains several nuclear facilities fully operational with current and approved authorization bases. These fully operational facilities include the ACRR facility (Haz Cat 2), Sandia Pulsed Reactor (SPR) facility (Haz Cat 2), and the Gamma Irradiation Facility (GIF) (Haz Cat 3). Other radiological facilities also exist in TA-V. Two other facilities, the Hot Cell Facility and the Auxiliary Hot Cell Facility also exist in TA-V but are currently not operational. An aerial view of TA-V is shown in Figure 13.

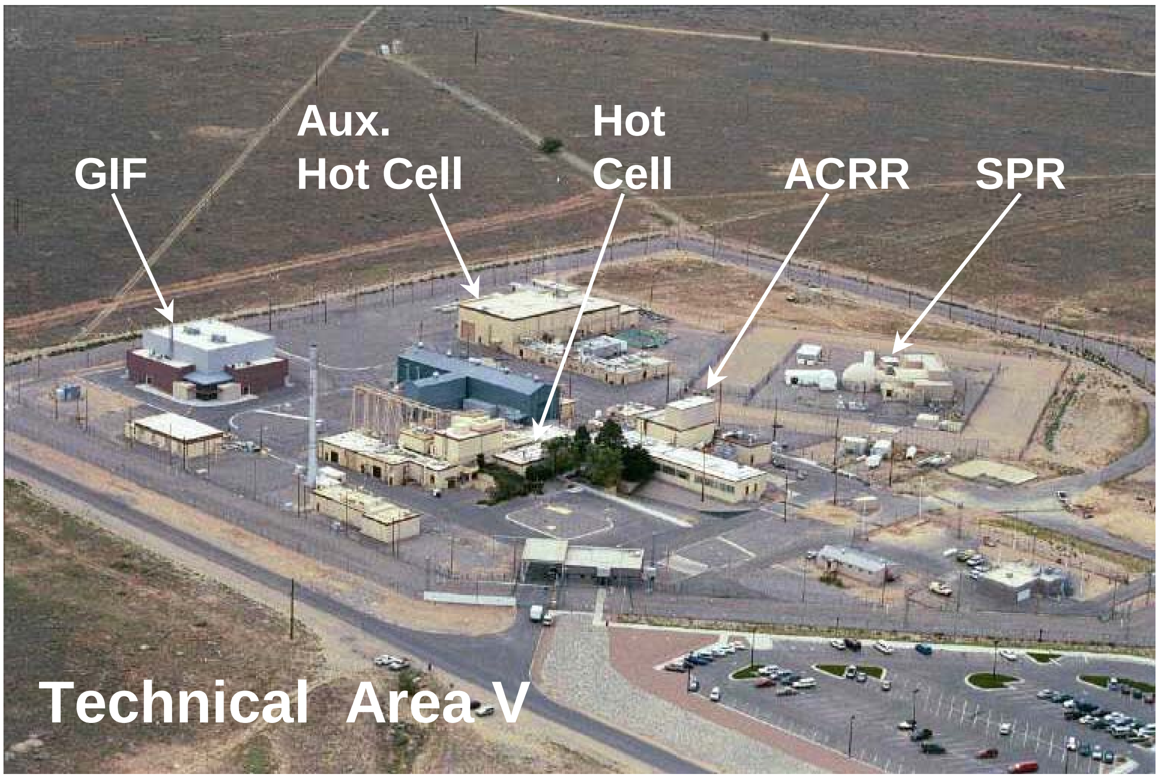

Figure 13. Facilities Located at Sandia National Laboratories Technical Area V.

The current plan would be to use the GIF for receiving the shipping container, unloading the rodlets, temporary storage, and loading the experiment package. Experiments requiring a glovebox or shielded glovebox could be performed in the GIF, ACRR facility, or SPR facility. The capsule would be transferred to the ACRR facility using a shielded on-site transfer container, if shielding was required. After testing at the ACRR, the experiment package would be stored at the ACRR facility for a limited period of time. NDE PIE would also be performed at the ACRR facility. Repackaging for shipping would again be performed at the GIF.

5.1 Annular Core Research Reactor

The ACRR facility is a Haz Cat 2 facility that provides the radiation environment for the fuels testing described within this document. The ACRR, shown in Figure 14, is an under-moderated pool-type reactor designed for both steady-state and transient-mode operations. The ACRR core is located in an open pool 3.1 m in diameter and 8.5 m deep. The pool is filled with 64,000 liters of deionized water. The core is cooled by natural convection of the pool water. The pool is cooled by a heat exchanger and cooling tower. For steady-state mode operations, the ACRR operates continuously at up to 2 MW but is approved to operate at up to 4 MW. The pool is cooled using a heat rejection system rated to 5 MW. For transient operations, the ACRR can operate in a pulse mode or programmed transient rod withdrawal mode. Total core yield for the transient mode is 300 MJ to 350 MJ integrated energy yield. A dry central cavity, nine inches in diameter, extends through the center of the core to the bottom of the pool and the top of the pool. A fueled-ring external cavity (FREC) can be attached to one side of the core to allow for irradiation of larger experiments. The FREC also maintains a dry cavity 20 in. in diameter.

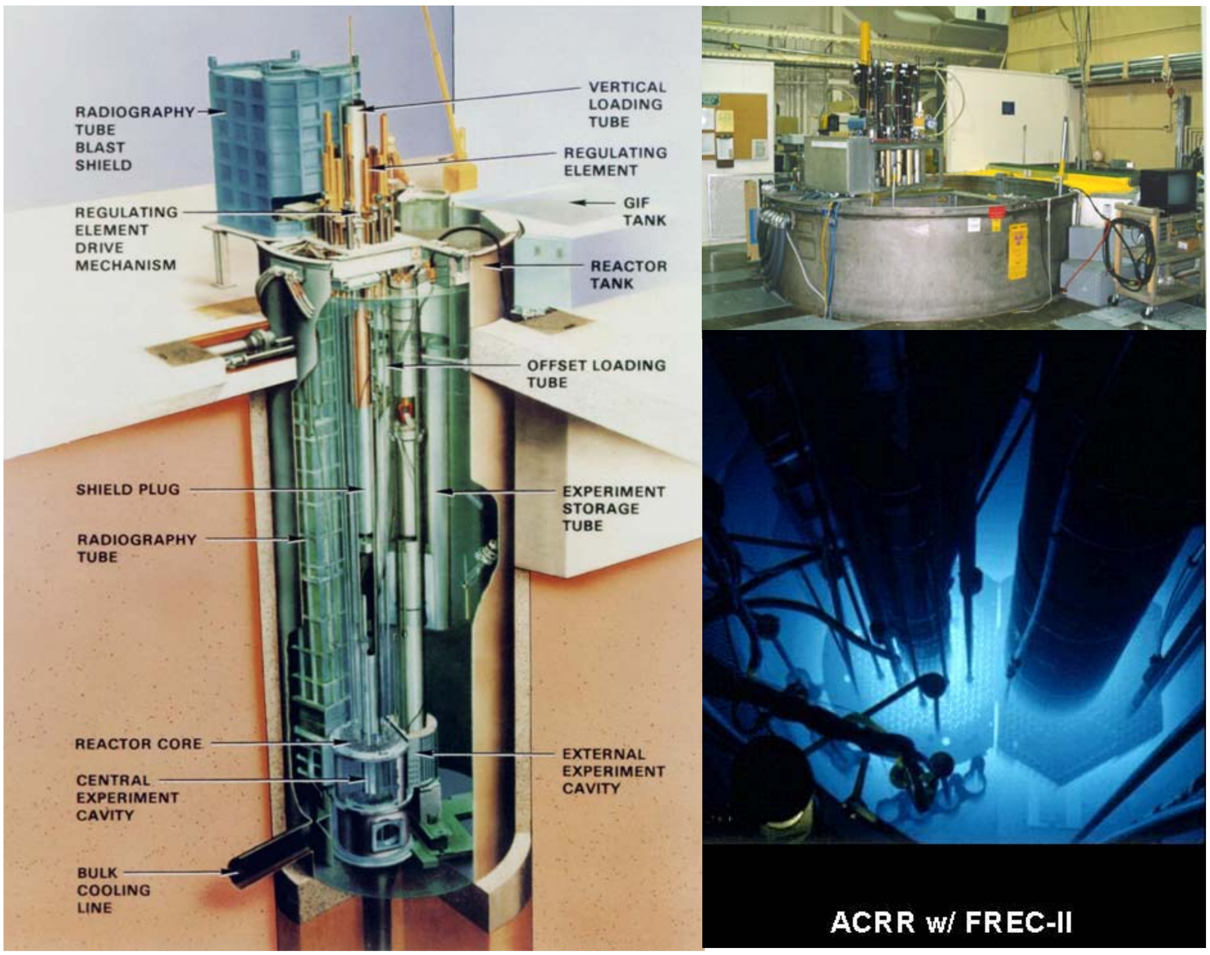

Figure 14. The Annular Core Research Reactor.

Because the ACRR is under-moderated, the neutron spectrum is epithermal within the central cavity. This epithermal spectrum can be modified by the use of thermal absorbers to give a harder spectrum or by the use of moderator materials to give a softer spectrum. Without moderation of the ACRR neutron spectrum in the central cavity, the coupling factor for the current fuel design is ~10 J/g_{fuel} per $MJ_{reactor}$. This coupling factor can be increased by about a factor of five by including moderating materials (e.g. polyethylene) in the central cavity. See Section 3.1 for more details related to the coupling factor implications for GNEP type fuels.

The ACRR facility also maintains a large high bay with two bridge cranes, a secondary 16 ft. deep storage pool, a number of lined storage holes (30 ft deep), and a highly shielded double cell area with manipulators, windows, and isolated ventilation. Although a glovebox does not currently exist in the ACRR facility, past experimental programs have integrated their own shielded glovebox into the facility. Large Type B shipping containers have also been unloaded and loaded within the ACRR high bay in the past.

5.2 TA-V Support Facilities

The TA-V support facilities include the GIF and SPR facility that are currently operational. Several radiological control areas also exist at different facilities within TA-V. It is expected that a glovebox or shielded glovebox could be installed within any of these facilities. The authorization basis approval to operate the glovebox with, for example, damaged fuel from a transient experiment, would be required. This might be difficult depending on the facility, its authorization basis, and its ventilation. However, this would need to be resolved if damaged fuel were to be repackaged for shipment from SNL.

The GIF is a Hazard Category 3 facility that is designed with a large high bay, bridge crane, 16-ft deep pool, and three large well-shielded cells with manipulators and windows. Large casks can be unloaded and loaded in the high-bay area. No gloveboxes currently exist in the GIF.

The SPR facility is a Hazard Category 2 facility designed to operate the Sandia Pulsed Reactor and other critical experiment campaigns. The SPR mission has been terminated which allows the potential for several areas that could be used for glovebox service. No gloveboxes currently exist in the SPR facility but have been temporarily used in the past to support experiment campaigns.

The current missions within TA-V do not require the use of hot cell facilities. Without programmatic support for these facilities, the DSAs have not been pursued or maintained. SNL corporate funds were expended on the cleanup of the SNL Hot Cell Facility (HCF) in preparation for the Mo-99 Isotope Production Program in the 1990s. It is expected that a substantial program would be required before SNL management would permit the recontamination of that facility. The HCF maintains shielded stainless-steel boxes, manipulators, and shielded windows, and is capable of supporting Haz Cat 2 materials. However the facility is currently not operational and does not have an approved DSA.

In summary, TA-V maintains a number of facilities that could be used to support the GNEP fuels testing program. The GIF is capable of handling Haz Cat 3 materials and is currently approved for use. No gloveboxes or shielded gloveboxes are currently in use at the GIF facility. The SPR facility and the ACRR facility are Haz Cat 2 facilities that could be used for cask unloading and experiment preparation for Haz Cat 3 or Haz Cat 2 materials. Again no gloveboxes exist at these facilities, but could be incorporated if required for the GNEP program. The HCF is currently not operational and does not have an approved DSA.

6 SCHEDULE AND FUNDING PROFILE

A high-level schedule, similar to that shown in Figure 12 is shown in Figure 15, depicting some of the major activities that would be required at each stage of the project. These figures, the other information presented in this report, and expert based input, was used to develop a draft project plan for transient fuels testing through FY 2012. The activities delineated in this project plan and a screen capture of the project plan is included in Appendix A. The current plan allows for fresh fuel testing (with and without Am-241 loading) in FY 2009.

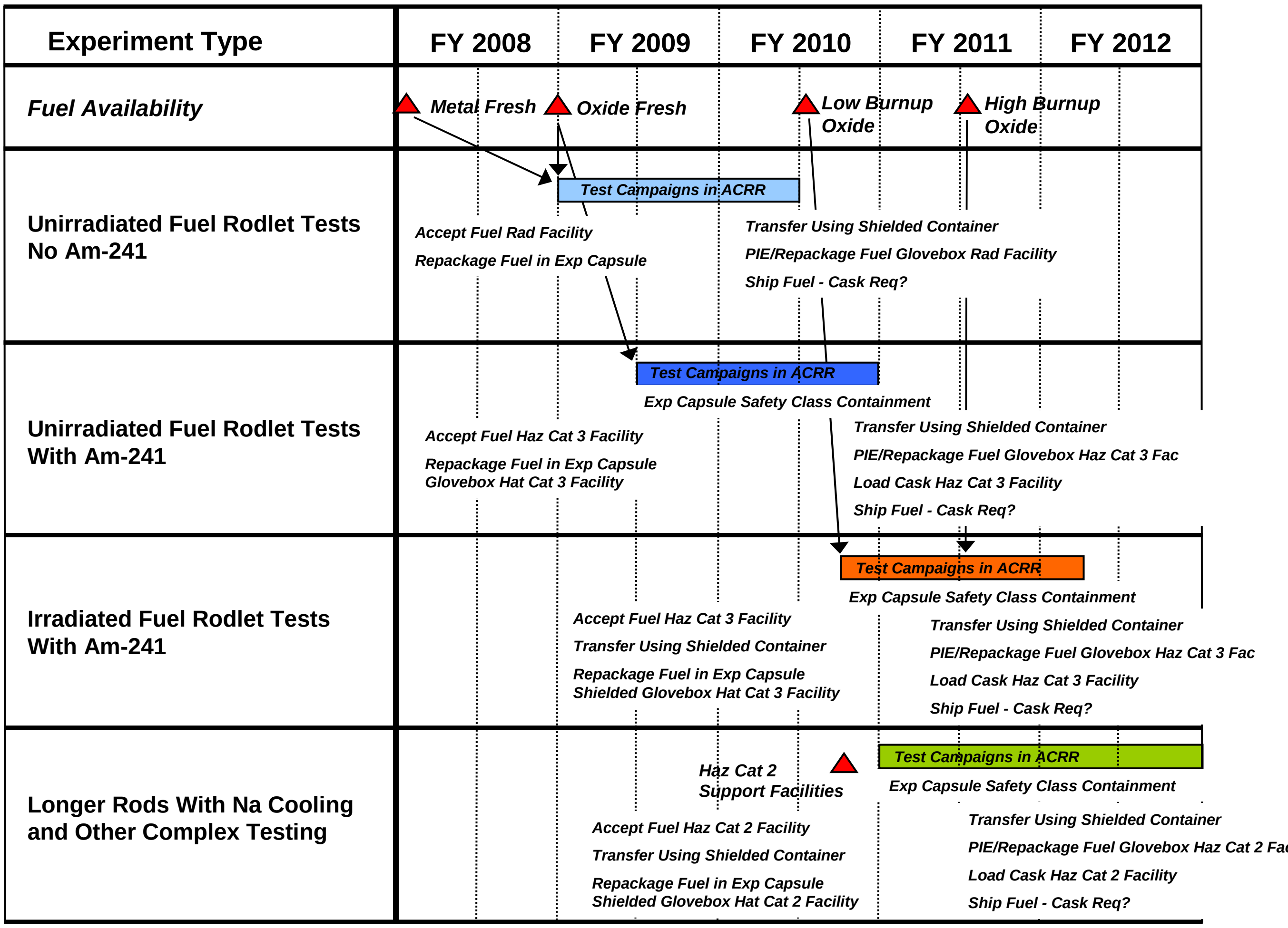

Figure 15. Proposed High-Level Schedule for ACRR Fuels Testing Showing the Major Activities and Fuel Availability.

The activities for FY 2008 and FY 2009 are condensed and summarized in the following lists. Required full time equivalents (FTEs) and projected budget requirements for each major activity are shown. Budget requirements for activities that require hardware show the estimated hardware budget as the second value in the list. These budget estimates, although somewhat subjective, represent a realistic estimate in performing the scope of work outlined in this document for the timeline for testing shown in Figures 12 and 15. Decreasing the scope and allowing slip in the testing would result in lower budget estimates.

The major assumptions in the scope of work for the funding profile for FY 2008 and FY 2009 are as follows:

- ACRR transient testing using fresh fuels (with and without Am-241) in FY 2009;
- ACRR transient testing using irradiated fuels in FY 2010;
- No destructive PIE performed at SNL;
- Non-destructive PIE (x-ray tomography, neutron radiograph, gamma scan, etc.) performed at SNL depending on experiment;
- No start up of a hot cell facility or other Haz Cat 2 or Haz Cat 3 facility at SNL – existing approved facilities would only be used for the current scope of work.

FY2008

• **Develop detailed project plan**	**0.1 FTE 30K**
• **Determine FY09 experiments and fuel availability**	**0.2 FTE 60K**
• **Identify shipping cask options and facility requirements (unirradiated)**	**0.5 FTE 150K**
• **Complete SNL ES&H requirements and TAV QA plan**	**0.5 FTE 150K**
• **Determine Safety Class containment requirements**	**0.5 FTE 150K**
• **Design FY09 experiments, diagnostics, exp capsule, on-site transfer container**	**1.5 FTE 450K**
• **Fabricate exp capsule and on-site transfer container**	**0.2 FTE 60K+ 200K**
• **Determine facility support requirements for FY09 tests**	**1.0 FTE 300K**
• **Modify facilities for shipping cask, exp handling, repackaging, and PIE**	**1.0 FTE 300K+150K**
• **Review DSAs and write and approve exp plan – unirradiated tests**	**2.0 FTE 600K**
• **Procedures for fuel receipt, handling, repackaging, ACRR testing**	**1.0 FTE 300K**
• **Begin receiving fresh fuel**	**0.2 FTE 60K**
TOTAL FY08	**8.7 FTE 2960K**

FY2009

• **Perform experiment campaigns for fresh fuel**	**1.5 FTE 450K + 200K**
• **Begin receiving fresh fuel with Am-241**	**0.2 FTE 60K**
• **Perform experiment campaigns for fresh fuel with Am-241**	**1.5 FTE 450K + 200K**
• **Determine FY10/FY11 experiments and fuel availability (irradiated)**	**0.2 FTE 60K**
• **Identify shipping cask options and facility requirements (irradiated)**	**0.5 FTE 150K**
• **Design FY10 experiments, diagnostics, exp capsule**	**1.5 FTE 450K**
• **Determine facility support requirements for FY10 tests**	**1.0 FTE 300K**
• **Review DSAs and write and approve exp plan – irradiated tests**	**1.0 FTE 300K**
• **Procedures for fuel receipt, handling, repackaging, ACRR testing – irradiated**	**0.5 FTE 150K**
• **Begin receiving irradiated fuel**	**0.2 FTE 60K**
• **Begin evaluating/planning Haz Cat 2 type experiments**	**0.5 FTE 150K**
TOTAL FY09	**6.6 FTE 2980K**

7 CONCLUSIONS

Transient testing is required for new fuel forms developed for the GNEP program in order to understand the behavior of the fuel and cladding at the design limit and failure limit. Comparative experiments using different types of fuel, fuel loadings, and burnup are required to understand fuel performance as a function of these parameters, and to eventually make a down selection to the initial transmutation fuel for the ABR. Nuclear heating tests are the only methods for achieving the fuel/clad temperature profile and transient testing conditions. We propose ACRR testing using simple, straight forward experiments and available fuel rodlets during the next few years that allow for the performance limits of the fuels forms to be evaluated irrespective of the reactor transient conditions. Later years may focus on transient conditions as the ABR design and safety envelope develops. As a down selection to ABR fuel is made in the following years, full fuel pin testing experiment in the ACRR can be evaluated.

A schedule through FY 2012 and budget projection for FY 2008 and FY 2009 has been proposed that would allow for fresh fuel testing in FY 2009. The schedule and budget are consistent with the scope of work delineated in this report.

8 REFERENCES AND SUPPORT DOCUMENTATION

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9 APPENDIX A – ACRR FUELS TESTING ACTIVITIES AND PROJECT PLAN

Nomenclature
<Haz Cat 3 activities – Fresh fuel, no Am-241, limited Pu to below Hazard Category 3 Threshold, not Safety Class equipment

Haz Cat 3 activities – Fresh fuel with Am-241 and irradiated fuel with Am-241, less than Hazard Category 2 Threshold, Safety Class equipment required

Haz Cat 2 activities – Fresh fuel with Am-241 and irradiated fuel with Am-241 above Hazard Category 2 Threshold – longer rodlets and multiple pins cooled by liquid metal or flowing gas.

<u>Activities FY 2008 ($2.96M)</u>
Develop initial experiment campaigns and diagnostic requirements
Develop QA plan for testing at ACRR
Perform NEPA for testing at ACRR
Determine Safety Class requirements for experiment capsule
Design and fabricate experiment capsule – to Safety Class requirements for up to Hazard Category 2 tests
Develop procedure for Safety Class equipment validation
Determine shipping methods for pre- and post-test. Identify casks and Safety Analysis Report for Packaging (SARP) modifications

Plan <Haz Cat 3 activities – receiving, experiment loading, PIE, repackaging, shipping
Determine facilities to be used for <Haz Cat 3 activities
Design and fabricate support hardware required for <Haz Cat 3 activities
Review DSAs for <Haz Cat 3 activities
Perform USQDs as necessary for <Haz Cat 3 tests
Develop experiment plan and procedures for <Haz Cat 3 tests

Plan Haz Cat 3 activities – receiving, experiment loading, PIE, repackaging, shipping
Determine facilities to be used for Haz Cat 3 activities
Design and fabricate support hardware required for Haz Cat 3 activities
Review DSAs for Haz Cat 3 activities
Perform USQDs as necessary for Haz Cat 3 tests

Plan Haz Cat 2 facility requirements
Determine facilities to be used for Haz Cat 2 activities

<u>Activities FY 2009 ($2.98M)</u>
Continue developing experiment campaigns and diagnostic requirements

Receive fuel for <Haz Cat 3 tests
Load experiment capsule for <Haz Cat 3 tests
Perform <Haz Cat 3 tests (number of tests unknown)

Perform PIE <Haz Cat 3 tests
Repackage and ship <Haz Cat 3 tested fuel

Receive fuel for Haz Cat 3 tests
Load experiment capsule for Haz Cat 3 tests
Perform Haz Cat 3 tests (number of tests unknown)
Perform PIE Haz Cat 3 tests
Repackage and ship Haz Cat 3 tested fuel

Develop specific requirements and handling procedures for Haz Cat 3 irradiated fuels

Haz Cat 2 facility modifications
Haz Cat 2 facility DSA

Activities FY 2010
Continue developing experiment campaigns and diagnostic requirements

Revisit NEPA requirements

Continue <Haz Cat 3 tests
Continue Haz Cat 3 tests
Receive Haz Cat 3 irradiated fuels
Begin Haz Cat 3 tests with irradiated fuels (number of tests unknown)

Haz Cat 2 facility modifications complete
Haz Cat 2 facility DSA complete
Readiness Assessment for Haz Cat 2 facility

Design and fabricate experiment capsule for Haz Cat 2 tests
Design and fabricate support hardware required for Haz Cat 2 activities

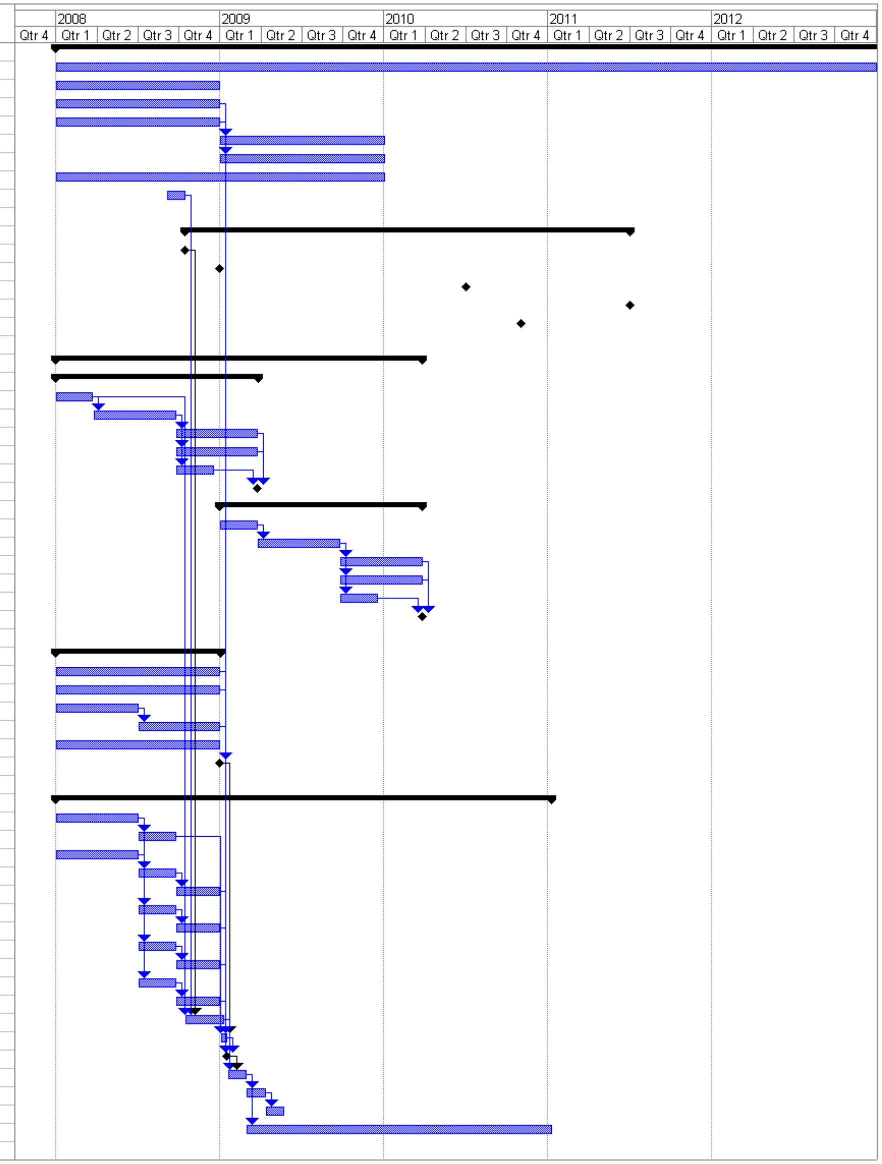
Begin receiving fuel for Haz Cat 2 tests

Activities FY 2011
Continue <Haz Cat 3 tests
Continue Haz Cat 3 tests

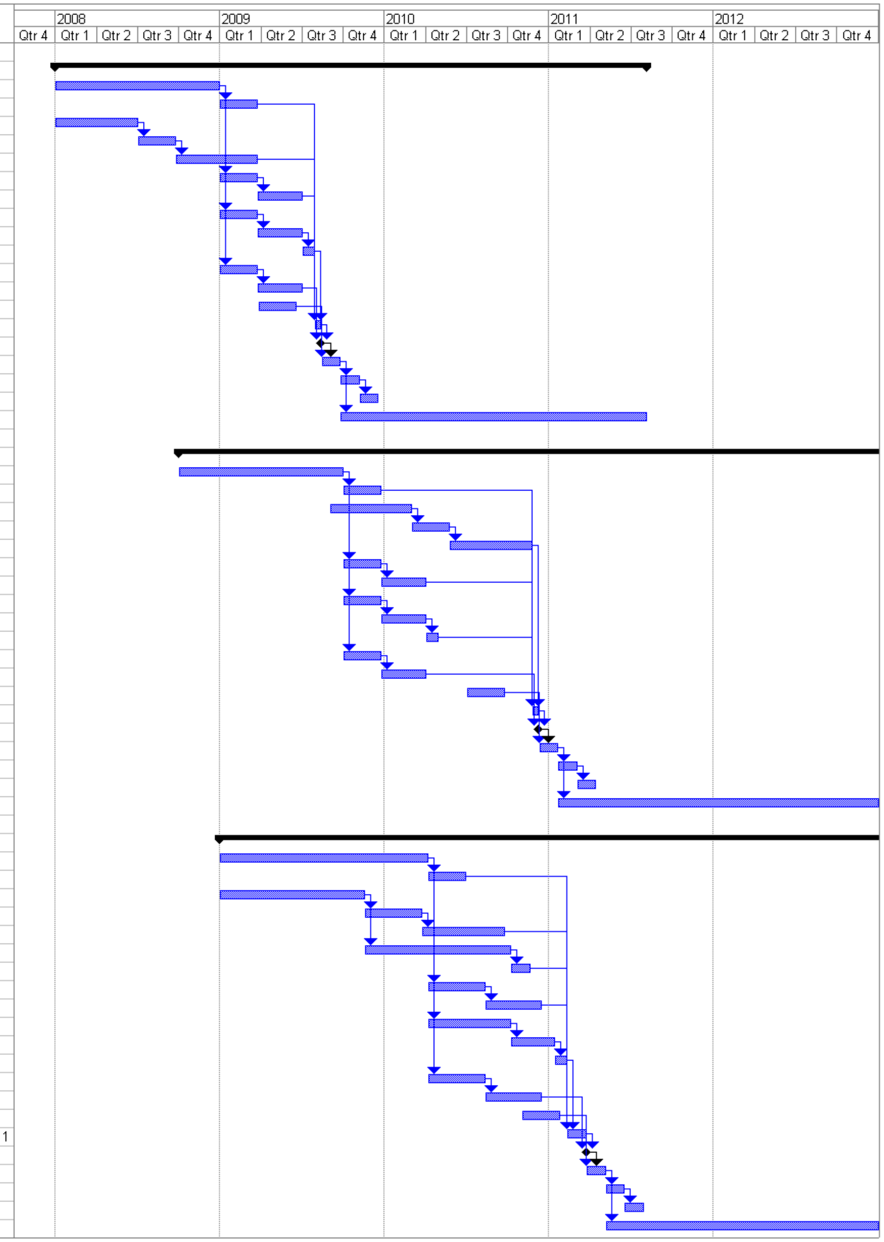
Load experiment capsule for Haz Cat 2 tests
Perform Haz Cat 2 tests (number of tests unknown)
Perform PIE Haz Cat 2 tests
Repackage and ship Haz Cat 2 tested fuel

Activities FY 2012
Continue <Haz Cat 3 tests
Continue Haz Cat 3 tests
Continue Haz Cat 2 tests

ID	WBS	Task Name	Duration	Start	Finish	Predecessors
1	1	**ACRR Transient Fuels Testing - Project Management**	**1306 days**	**Mon 10/1/07**	**Mon 10/1/12**	
2	1.1	Project Management	1306 days	Mon 10/1/07	Mon 10/1/12	
3	1.2	Develop Detailed Project Plan	262 days	Mon 10/1/07	Tue 9/30/08	
4	1.3	Determine Initial Experiment Campaigns (Fresh and Irradiated)	262 days	Mon 10/1/07	Tue 9/30/08	
5	1.4	Determine Diagnostic Requirements for Initial Campaigns (In-Pile, PIE)	262 days	Mon 10/1/07	Tue 9/30/08	
6	1.5	Determine Follow-On Experiment Campaigns (Rods and Complex)	262 days	Wed 10/1/08	Thu 10/1/09	4
7	1.6	Determine Diagnostic Requirements for Follow-On Campaigns	262 days	Wed 10/1/08	Thu 10/1/09	5
8	1.7	Determine Fuel Availability to Meet Exp. Campaign Goals	524 days	Mon 10/1/07	Thu 10/1/09	
9	1.8	Agreement to Accept and Ship Fuel (DOE,INL,SNL)	30 days	Tue 6/3/08	Mon 7/14/08	
10						
11	2	**Fuel Availability**	**709 days?**	**Tue 7/15/08**	**Fri 4/1/11**	
12	2.1	Fresh Fuel Available for Rodlet Tests (w/o Am-241)	1 day?	Tue 7/15/08	Tue 7/15/08	
13	2.2	Fresh Fuel Available for Rodlet Tests (w/ Am-241)	1 day?	Wed 10/1/08	Wed 10/1/08	
14	2.3	Irradiated Fuel Available (Low Burnup)	1 day?	Thu 4/1/10	Thu 4/1/10	
15	2.4	Irradiated Fuel Available (High Burnup)	1 day?	Fri 4/1/11	Fri 4/1/11	
16	2.5	Pin Scale Fuel Available (Fresh)	1 day?	Mon 8/2/10	Mon 8/2/10	
17						
18	3	**Shipping Requirements**	**585 days?**	**Mon 10/1/07**	**Fri 12/25/09**	
19	**3.1**	**Shipping Container for Unirradiated Fuels**	**323 days?**	**Mon 10/1/07**	**Wed 12/24/08**	
20	3.1.1	Determine Shipping Methods and Cask Options	60 days	Mon 10/1/07	Fri 12/21/07	
21	3.1.2	Review Cask SARPs to Determine Issues for Intact and Damaged Fuel	131 days	Mon 12/24/07	Mon 6/23/08	20
22	3.1.3	Modify SARP and Attain SARP Approvals	131 days	Tue 6/24/08	Tue 12/23/08	21
23	3.1.4	Facility Modifications for Handling Cask	131 days	Tue 6/24/08	Tue 12/23/08	21
24	3.1.5	Training and Certification	60 days	Tue 6/24/08	Mon 9/15/08	21
25	3.1.6	Shipping and Receiving Req Met for Unirradiated Fuels	1 day?	Wed 12/24/08	Wed 12/24/08	24,23,22
26	**3.2**	**Shipping Container for Irradiated Fuels**	**323 days?**	**Wed 10/1/08**	**Fri 12/25/09**	
27	3.2.1	Determine Shipping Methods and Cask Options	60 days	Wed 10/1/08	Tue 12/23/08	
28	3.2.2	Review Cask SARPs to Determine Issues for Intact and Damaged Fuel	131 days	Wed 12/24/08	Wed 6/24/09	27
29	3.2.3	Modify SARP and Attain SARP Approvals	131 days	Thu 6/25/09	Thu 12/24/09	28
30	3.2.4	Facility Modifications for Handling Cask	131 days	Thu 6/25/09	Thu 12/24/09	28
31	3.2.5	Training and Certification	60 days	Thu 6/25/09	Wed 9/16/09	28
32	3.2.6	Shipping and Receiving Req Met for Irradiated Fuels	1 day?	Fri 12/25/09	Fri 12/25/09	31,30,29
33						
34	4	**Safety Process (Generic)**	**263 days?**	**Mon 10/1/07**	**Wed 10/1/08**	
35	4.1	Develop SNL/Area V QA Plan	262 days	Mon 10/1/07	Tue 9/30/08	
36	4.2	Perform Initial SNL NEPA Documentation	262 days	Mon 10/1/07	Tue 9/30/08	
37	4.3	Determine Safety Class Requirements for Experiment Capsule	131 days	Mon 10/1/07	Mon 3/31/08	
38	4.4	Develop Procedure for Safety Class Containment - Requ. And Testing	131 days	Tue 4/1/08	Tue 9/30/08	37
39	4.5	Perform SNL Preliminary Haz Assessment Process	262 days	Mon 10/1/07	Tue 9/30/08	
40	4.6	SNL Initial Safety Process Complete	1 day?	Wed 10/1/08	Wed 10/1/08	35,36,38
41						
42	5	**Transient Testing - <Haz Cat 3 (w/o Am-241)- No SCE - Minimal Shielding**	**789 days?**	**Mon 10/1/07**	**Thu 10/7/10**	
43	5.1	Design <Haz Cat 3 Experiments - Req., Diagnostics, Etc.	131 days	Mon 10/1/07	Mon 3/31/08	
44	5.2	Plan <Haz Cat 3 Activities - Receiving, Exp Loading, PIE, Repackaging, Shipping	60 days	Tue 4/1/08	Mon 6/23/08	43
45	5.3	Determine Support Facility Requirements	131 days	Mon 10/1/07	Mon 3/31/08	
46	5.4	Review DSAs	60 days	Tue 4/1/08	Mon 6/23/08	45
47	5.5	Perform USQDs	70 days	Tue 6/24/08	Mon 9/29/08	46
48	5.6	Develop Exp Plan	60 days	Tue 4/1/08	Mon 6/23/08	43
49	5.7	Safety Approval of Exp Plan	70 days	Tue 6/24/08	Mon 9/29/08	48
50	5.8	Design Experiment Capsule for Tests	60 days	Tue 4/1/08	Mon 6/23/08	43
51	5.9	Fabricate Capsules	70 days	Tue 6/24/08	Mon 9/29/08	50
52	5.10	Design Support Hardware	60 days	Tue 4/1/08	Mon 6/23/08	43
53	5.11	Fabricate Support Hardware	70 days	Tue 6/24/08	Mon 9/29/08	52
54	5.12	Begin Receipt of Fuel	60 days	Wed 7/16/08	Tue 10/7/08	9,20,44,12
55	5.13	Readiness Assessment	10 days	Thu 10/2/08	Wed 10/15/08	47,49,40,44
56	5.14	Ready to Perform 1st <Haz Cat 3 Exp	1 day?	Thu 10/16/08	Thu 10/16/08	55,51,53,5
57	5.15	Perform 1st Experiment - Load, Operate, Store, PIE	30 days	Fri 10/17/08	Thu 11/27/08	56,54
58	5.16	Repackage Fuel for Return Shipment - 1st	30 days	Fri 11/28/08	Thu 1/8/09	57
59	5.17	Ship Fuel - Return - 1st	30 days	Fri 1/9/09	Thu 2/19/09	58
60	5.18	Continue Experiments - Fuel Receipt, Run Exp, PIE, Ship	485 days	Fri 11/28/08	Thu 10/7/10	57
61						



ID	WBS	Task Name	Duration	Start	Finish	Predecessors
61						
62	**6**	**Transient Testing - Haz Cat 3 (w/ Am-241) - SCE - Minimal Shielding**	**938 days?**	**Mon 10/1/07**	**Wed 5/4/11**	
63	6.1	Design Haz Cat 3 Experiments - Req., Diagnostics, Etc.	262 days	Mon 10/1/07	Tue 9/30/08	
64	6.2	Plan Haz Cat 3 Activities - Receiving, Exp Loading, PIE, Repackaging, Shipping	60 days	Wed 10/1/08	Tue 12/23/08	63
65	6.3	Determine Support Facility Requirements	131 days	Mon 10/1/07	Mon 3/31/08	
66	6.4	Review DSAs	60 days	Tue 4/1/08	Mon 6/23/08	65
67	6.5	Perform USQDs	131 days	Tue 6/24/08	Tue 12/23/08	66
68	6.6	Develop Exp Plan	60 days	Wed 10/1/08	Tue 12/23/08	63
69	6.7	Safety Approval of Exp Plan	70 days	Wed 12/24/08	Tue 3/31/09	68
70	6.8	Design Experiment Capsule for Tests	60 days	Wed 10/1/08	Tue 12/23/08	63
71	6.9	Fabricate Capsules	70 days	Wed 12/24/08	Tue 3/31/09	70
72	6.10	Perform Safety Class Validation on Exp Capsule	20 days	Wed 4/1/09	Tue 4/28/09	71
73	6.11	Design Support Hardware	60 days	Wed 10/1/08	Tue 12/23/08	63
74	6.12	Fabricate Support Hardware	70 days	Wed 12/24/08	Tue 3/31/09	73
75	6.13	Begin Receipt of Fuel	60 days	Thu 12/25/08	Wed 3/18/09	13,25
76	6.14	Readiness Assessment	10 days	Wed 4/29/09	Tue 5/12/09	67,69,72,64
77	6.15	Ready to Perform 1st Haz Cat 3 Exp	1 day?	Wed 5/13/09	Wed 5/13/09	76,74,5
78	6.16	Perform 1st Experiment - Load, Operate, Store, PIE	30 days	Thu 5/14/09	Wed 6/24/09	77,75
79	6.17	Repackage Fuel for Return Shipment - 1st	30 days	Thu 6/25/09	Wed 8/5/09	78
80	6.18	Ship Fuel - Return - 1st	30 days	Thu 8/6/09	Wed 9/16/09	79
81	6.19	Continue Experiments - Fuel Receipt, Run Exp, PIE, Ship	485 days	Thu 6/25/09	Wed 5/4/11	78
82						
83	**7**	**Transient Testing - Haz Cat 3 (w/ Am-241 Irradiated) - SCE - Shielding**	**1162 days?**	**Tue 7/1/08**	**Wed 12/12/12**	
84	7.1	Design Haz Cat 3 Experiments - Req., Diagnostics, Etc.	262 days	Tue 7/1/08	Wed 7/1/09	
85	7.2	Plan Haz Cat 3 Activities - Receiving, Exp Loading, PIE, Repackaging, Shipping	60 days	Thu 7/2/09	Wed 9/23/09	84
86	7.3	Determine Support Facility Requirements	131 days	Mon 6/1/09	Mon 11/30/09	
87	7.4	Review DSAs	60 days	Tue 12/1/09	Mon 2/22/10	86
88	7.5	Perform USQDs	131 days	Tue 2/23/10	Tue 8/24/10	87
89	7.6	Develop Exp Plan	60 days	Thu 7/2/09	Wed 9/23/09	84
90	7.7	Safety Approval of Exp Plan	70 days	Thu 9/24/09	Wed 12/30/09	89
91	7.8	Design Experiment Capsule for Tests	60 days	Thu 7/2/09	Wed 9/23/09	84
92	7.9	Fabricate Capsules	70 days	Thu 9/24/09	Wed 12/30/09	91
93	7.10	Perform Safety Class Validation on Exp Capsule	20 days	Thu 12/31/09	Wed 1/27/10	92
94	7.11	Design Support Hardware	60 days	Thu 7/2/09	Wed 9/23/09	84
95	7.12	Fabricate Support Hardware	70 days	Thu 9/24/09	Wed 12/30/09	94
96	7.13	Begin Receipt of Fuel	60 days	Fri 4/2/10	Thu 6/24/10	14,32
97	7.14	Readiness Assessment	10 days	Wed 8/25/10	Tue 9/7/10	88,90,93,85
98	7.15	Ready to Perform 1st Haz Cat 3 Shielded Exp	1 day?	Wed 9/8/10	Wed 9/8/10	97,95,5
99	7.16	Perform 1st Experiment - Load, Operate, Store, PIE	30 days	Thu 9/9/10	Wed 10/20/10	98,96
100	7.17	Repackage Fuel for Return Shipment - 1st	30 days	Thu 10/21/10	Wed 12/1/10	99
101	7.18	Ship Fuel - Return - 1st	30 days	Thu 12/2/10	Wed 1/12/11	100
102	7.19	Continue Experiments - Fuel Receipt, Run Exp, PIE, Ship	560 days	Thu 10/21/10	Wed 12/12/12	99
103						
104	**8**	**Transient Testing - Haz Cat 2- Longer Rods, Na Cooling, Other Complex Exp.**	**1171 days?**	**Wed 10/1/08**	**Wed 3/27/13**	
105	8.1	Design Haz Cat 2 Experiments - Req., Diagnostics, Etc.	330 days	Wed 10/1/08	Tue 1/5/10	
106	8.2	Plan Haz Cat 2 Activities - Receiving, Exp Loading, PIE, Repackaging, Shipping	60 days	Wed 1/6/10	Tue 3/30/10	105
107	8.3	Determine Support Facility Requirements	230 days	Wed 10/1/08	Tue 8/18/09	
108	8.4	Review DSAs	90 days	Wed 8/19/09	Tue 12/22/09	107
109	8.5	Perform USQDs	131 days	Wed 12/23/09	Wed 6/23/10	108
110	8.6	Modify Facility for Haz Cat 2 Requirements	232 days	Wed 8/19/09	Thu 7/8/10	107
111	8.7	Readiness Review of Modified Haz Cat 2 Facility	30 days	Fri 7/9/10	Thu 8/19/10	110
112	8.8	Develop Exp Plan	90 days	Wed 1/6/10	Tue 5/11/10	105
113	8.9	Safety Approval of Exp Plan	90 days	Wed 5/12/10	Tue 9/14/10	112
114	8.10	Design Experiment Capsule for Tests	130 days	Wed 1/6/10	Tue 7/6/10	105
115	8.11	Fabricate Capsules	70 days	Wed 7/7/10	Tue 10/12/10	114
116	8.12	Perform Safety Class Validation on Exp Capsule	20 days	Wed 10/13/10	Tue 11/9/10	115
117	8.13	Design Support Hardware	90 days	Wed 1/6/10	Tue 5/11/10	105
118	8.14	Fabricate Support Hardware	90 days	Wed 5/12/10	Tue 9/14/10	117
119	8.15	Begin Receipt of Fuel	60 days	Tue 8/3/10	Mon 10/25/10	16,32
120	8.16	Readiness Assessment	30 days	Wed 11/10/10	Tue 12/21/10	109,113,116,111
121	8.17	Ready to Perform 1st Scale-Up Exp	1 day?	Wed 12/22/10	Wed 12/22/10	120,118,7
122	8.18	Perform 1st Experiment - Load, Operate, Store, PIE	30 days	Thu 12/23/10	Wed 2/2/11	121,119
123	8.19	Repackage Fuel for Return Shipment - 1st	30 days	Thu 2/3/11	Wed 3/16/11	122
124	8.20	Ship Fuel - Return - 1st	30 days	Thu 3/17/11	Wed 4/27/11	123
125	8.21	Continue Experiments - Fuel Receipt, Run Exp, PIE, Ship	560 days	Thu 2/3/11	Wed 3/27/13	122



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