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AN ESTIMATE OF SANDIA RESOURCES FOR UNDERGROUND NUCLEAR WEAPONS EFFECTS TESTING

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Abstract

We conducted a study of the time and resources that would be required for Sandia National Laboratories to once again perform nuclear weapons effects experiments of the sort that it did in the past. The study is predicated on the assumptions that if underground nuclear weapons effects testing (UG/NWET) is ever resumed, (1) a brief series of tests (i.e., 2-3) would be done, and (2) all required resources other than those specific to SNL experiments would be provided by others. The questions that we sought to answer were: (1) What experiments would SNL want to do and why? (2) How much would they cost? (3) How long would they take to field? To answer these questions, we convened panels of subject matter experts first to identify five experiments representative of those that SNL has done in the past, and then to determine the costs and timelines to design, fabricate and field each of them. We found that it would cost $76M to $84M to do all five experiments, including 164 to 174 FTEs to conduct all five experiments in a single test. Planning and expenditures for some of the experiments needed to start as early as 5.5 years prior to zero-day, and some work would continue up to 2 years beyond the event. Using experienced personnel as mentors, SNL could probably field such experiments within the next five years. However, beyond that time frame, loss of personnel would place us in the position of essentially starting over.

Acknowledgements

We would like to thank the many subject-matter experts who contributed to this report either by serving on our expert panels and by reviewing and correcting our notes, or by providing supplementary information:

- Bill Barrett
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- Ivars Gals
- Toby Garcia
- Ken Glibert
- Fred Hartman
- Ron Hartwig
- Tom Hendrickson
- Jacque Hohlfelder
- Roy Holt
- Bill Kluesner
- Roy LeBlanc
- Jim Lee
- George Novotny
- Paul Raglin
- Ken Reil
- Byron Ristvet
- Fritz Roessler
- Charlie Sandoval
- Gary Scrivner
- Pat Sena
- Rod Shear
- Fred Hartman
- Bill Tedeschi
- Dave Thomson
- Rich Westfall
- Barton Wohl

We would especially like to thank Frank Dean and Dave Beutler, who reviewed this report for technical accuracy. However, the authors assume final responsibility for any errors or omissions.

Finally, we would like to thank Judy Fahlberg for formatting the final version of this report and shepherding it through the publication process.

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Executive Summary

This study was commissioned by Sandia National Laboratories' (SNL) Program Director Leadership Team (PDLT) in the fall of 2002, in response to suggestions by Federal government officials that the nation's readiness to resume underground testing should be shortened from two-to-three years to eighteen months. The National Nuclear Security Agency's Underground Test Readiness Program strictly applies only to nuclear weapon development and performance tests, in which Sandia played only a peripheral role: Los Alamos and Lawrence Livermore National Laboratories were the principals in this type of underground test. Sandia was, however, a key participant in underground *nuclear weapons effects* tests (UG/NWET), and any proposed changes to the nation's test readiness posture could be of interest to SNL.

The PDLT thought that it would be prudent to be able to answer three questions in the event that future effects testing should be considered: (1) What experiments would SNL want to do and why? (2) How much would they cost? (3) How long would they take to field? SNLs' Systems Analysis Group 9810 was asked to find the answers to these questions. Our results are presented in this report.

Five types of experiments stood out as strong candidates should effects testing resume. These are (1) Operating war-reserve (WR) arming, fuzing and firing (AF&F) units during and after radiation exposure; (2) Measuring cable and cavity system-generated electromagnetic pulse (SGEMP) effects; (3) Measuring the effect of radiation on neutron generator performance during and after exposure; (4) Evaluating shielding materials in a radiation environment; and (5) Evaluating the effects of radiation exposure on explosive and pyrotechnic components.

It would cost between $76M and $84M in current dollars—including 164 to 174 FTEs—to design, fabricate, field, recover and analyze all of these experiments. Of this, approximately $22M would be a one-time investment in new computer and data recording hardware, building restoration, and other capital improvements the costs of which might be amortized over additional UG/NWETs. Costs for the individual experiments are broken out in the report.

Depending upon the particular experiment, expenditures might need to begin as early as 5.5 years prior to "zero-day," and continue up to 2 years past the event. The Shielding Materials experiment required the greatest lead time because our subject-matter experts believed that certain manufacturing processes needed to be revived before test specimens could be prepared. Experiments that required intensive post-test material analysis (Shielding Materials and Neutron Generators) ran the longest beyond zero-day. However, most activity is concentrated in the period from –3.5 years to +6 months.

These costs and times are optimistic, because our estimates were based on the use of experienced personnel. In fact, the dwindling number of experienced personnel is the single greatest threat to SNLs' ability to field such experiments in the future. Fully half of the people who served on the last effects test (Hunters Trophy, executed in 1992), are gone from the Labs. Half of those who remain could retire within the next five years. We

estimate that SNL could conceivably perform such a test within the next five years using experienced UG/NWET "hands" as mentors. Beyond five years, however, our assessment is that we would essentially be starting over.

List of Acronyms

ACRR	annular core research reactor
ASCI	Accelerated Strategic Computing Initiative
A&F	arming and firing
AF&F	arming, fuzing and firing
AGT	above-ground test
BN	Bechtel Nevada
CVT	current viewing transformer
DAS	data acquistion system
DNA	Defense Nuclear Agency
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DTE	differential themal expansion
DTRA	Defense Threat Reduction Agency
DTRAIAC	Defense Threat Reduction Agency Information Analysis Center
EMP	electromagnetic pulse
FTE	full-time equivalent (fully loaded)
HF	high frequency
HLOS	horizontal line-of-sight
K	thousands
LANL	Los Alamos National Laboratory
LF	low frequency
LLNL	Lawrence Livermore National Laboratory
LOS	line-of-sight
M	millions
Mid Freq	mid-frequency
Mgr.	manager
MUX	multiplexer
NG	neutron generator
NGA	neutron generator assembly

NNSA	National Nuclear Security Administration
NT	neutron tube
NTS	Nevada Test Site
NWSBU	Nuclear Weapons Strategic Business Unit
ODC	other direct charges
PDLT	Program Director Leadership Team
RB	re-entry body
RT	round trip
RV	re-entry vehicle
SGEMP	system-generated electromagnetic pulse
SME	subject-matter expert
SNL	Sandia National Laboratories
TBD	to be determined
Tech	technologist
TLD	total life dosimeter
TMS	thermomechanical shock
TOAD	time-of-arrival-detector
TSR	thermostructural response
UG/NWET	underground nuclear weapon effects test
UGT	underground test
V&V	validation and verification
WIPP	Waste Isolation Pilot Plant
WR	war reserve

1. INTRODUCTION AND BACKGROUND

Since September of 1992, the United States has adhered to a self-imposed moratorium on nuclear testing, relying instead on the U.S. Department of Energy's (DOE) Stockpile Stewardship Program to ensure the safety and reliability of the nation's nuclear weapons and their subcomponents.[1,2] However, since 1992 the DOE has also been charged by Presidential Directive with maintaining the capability to resume nuclear testing within a two- to three-year time period, should the President determine that testing is required.[1] This same Presidential Directive required DOE to establish a Test Readiness Program at the Nevada Test Site (NTS) to sustain this capability.

Within the last year there has been official discussion of reducing this test-readiness timeframe by a substantial—but unspecified—amount.[3,4] Moreover, there have been suggestions by Department of Defense (DoD) officials that resumption of full-scale nuclear testing may be either useful[5] or necessary[6] in order to ensure the safety and reliability of the stockpile. In his February, 2002 testimony on DOE's role in implementing the Nuclear Posture Review presented to the U.S. Senate Committee on Armed Services,[4] J.A. Gordon, then Administrator for the National Nuclear Security Agency (NNSA), made it clear that in the context of test readiness, "nuclear testing" means "*underground* nuclear testing" (UGT). This makes sense because the United States committed to refrain from atmospheric, space and underwater nuclear testing with its ratification of the Limited (or Partial) Test Ban Treaty of 1963.[2]

Sandia National Laboratories (SNL) has had a long, direct involvement with underground nuclear testing, of which there are two fundamental types. A detailed review of the manner in which these two types of tests were conducted is beyond the scope of this report. A somewhat older—but still very useful—layman's guide to underground testing may be found in reference [7].

Warheads designed by Los Alamos National Laboratory (LANL) or Lawrence Livermore National Laboratory (LLNL) were tested and evaluated in underground tests conducted in vertical shafts.[7] SNLs' involvement in these tests was limited to providing field-test neutron generators for both laboratories, and arming and firing systems for those tests conducted by LLNL. SNL also provided seismic monitoring. These "development and performance" tests, conducted by the DOE, focused on evaluating the safety, reliability and yield of nuclear weapons that were to be used on DoD weapon systems. It should be emphasized that since the 1992 UGT moratorium was imposed, DOE's test readiness program has only applied to these development and performance tests.

Sandia had much greater involvement in underground nuclear weapons effects tests (UG/NWETs), which were usually conducted in horizontal tunnels, in long, evacuated line-of-sight (LOS) pipes.[7] Here the emphasis was on evaluating the effects of radiation on both non-nuclear *and* nuclear materials, components and systems. X-ray effects were of the greatest interest. Gamma (γ) and neutron (n) radiation effects usually could be evaluated in above-ground experiments; however, occasionally, investigation of the effects of changes in γ exposure with time ($d\gamma/dt$) over large surface areas also required

UG/NWETs. These tests were conducted by the DoD for the purpose of evaluating the effects of nuclear weapons *on* nuclear weapon systems.

In addition to field-test neutron generators, arming and firing systems and seismic monitoring, SNL also provided other capabilities for UG/NWET under contract to the test sponsor, then the Defense Nuclear Agency (DNA). These included containment and LOS pipe radiation diagnostics, as well as special, fast-acting closures that protected recording equipment and other instrumentation from debris flow down the LOS pipe. SNL also conducted many of its own radiation effects experiments on components and materials of its own design or manufacture, for which it provided local and/or specialized radiation diagnostics. Examination of 1989 and 1992 SNL telephone books indicates that even at the conclusion of the era of underground effects tests, Sandia maintained the equivalent of about ten current departments that were directly dedicated to UGT, containing 90-100 full-time equivalent employees (FTEs). Examination of 1991 and 1992 budget data confirm anecdotal evidence that the annual budget for UGT at Sandia was approximately $50M then-year dollars.

As stated above, the interest in shortening the test-readiness time frame and the renewed interest in actual underground testing (for which the motivation remains vague), applies only to the performance and reliability tests in which SNL played a comparatively small role. Nevertheless, several members of SNLs' Nuclear Weapons Strategic Business Unit's (NWSBU) Program Directors Leadership Team (PDLT) thought it would be prudent to be able to answer several questions about Sandia's possible role in future underground *weapons effects* tests. Specifically, they wanted to know: (1) What experiments would we want to do and why? (2) How much would they cost? (3) How long would they take to field? SNLs' Systems Analysis Center 9810 was asked to find the answers to these questions. This report documents our findings.

2. BRIEFING SUMMARY

We were able to start with a recent internal memorandum that summarized a long list of experiments that SNL weapons program personnel would like to perform should UG/NWET ever resume.[8] We formed a panel composed of SNL staff with experience in both UG/NWET and the weapons programs, and asked the panel to reduce this list of experiments to five having particular mission-relevance, and which were also representative of the range of experiments that SNL conducted in the past. The five experiments included: (1) Operating a war reserve (WR) arming, fuzing and firing (AF&F) component during radiation exposure; (2) Measuring cable and cavity system-generated electromagnetic pulse (SGEMP) effects; (3) Measuring the effect of radiation on neutron generator performance during and after exposure; (4) Evaluating shielding materials in a radiation environment; and (5) Evaluating the effects of radiation exposure on explosive components.

Parenthetically, we remark that as time passes, these might not be the *exact* experiments that SNL would choose to do. However, we selected a wide range of experiment types and deliberately kept each of them somewhat generic; With some cost substitutions and proper overall cost escalation, these experiments and accompanying estimates could be useful for some time to come.

For each experiment, we formed an additional panel composed of personnel with more specialized experience to fully define the experiment's objectives and the resources and time required to complete it. Once all five of the experiments were completely defined, we convened a panel at NTS consisting of personnel with experience in fielding UG/NWET experiments, and asked them what resources and time would be required on Sandia's part to prepare the experiments. For all the panels, we limited our estimates to those resources required specifically for the Sandia experiments, and assumed that virtually all other infrastructure would be provided by the test sponsor, presumably the Defense Threat Reduction Agency (DTRA). This infrastructure would include (but not necessarily be limited to) the tunnel, line-of-sight (LOS) pipe, well-characterized nuclear device, radiation diagnostics, alignment, containment, *etc*.

After compiling all of the data, we found that over a period of approximately five years it would take \$76M to \$84M—including 164 to 174 FTEs—to design, fabricate, field, recover and analyze the experiments. Of this, approximately \$22M would be a one-time investment in new computer and data recording hardware, building restoration, and other capital improvements, the costs of which might be amortized over additional UG/NWETs, if more were ever performed. We assumed that new data acquisition equipment would be needed because technology has changed greatly in the decade since the last UG/NWET was performed. We further assumed that optical fiber would be used for all data acquisition, and that most—though not all—data would be recorded aboveground. The total cost is consistent with past annual budgets for SNL's core UGT organizations when it is remembered that (1) the costs are spread over roughly five years (\$15M-\$17M per year per test) and (2) SNL might typically have had three UGTs in planning, execution and analysis stages in the past (3×\$15M to \$17M=\$45M to \$51M).

One serious threat to SNLs' ability to field future UG/NWETs, however, is the loss of experienced personnel. In the course of our investigation, we have determined that underground nuclear weapons effects testing is as much art as science. After spending significant amounts of time in both the classified SNL archives and at the Defense Threat Reduction Agency's Information and Analysis Center (DTRAIAC), we have also determined that much of the art was apparently not well-documented. Workers on UG/NWETs were not considered experienced until they had served on at least three tests, preferably more. Examination of test plans for the last UG/NWET ever performed (Hunters Trophy, executed in 1992[9]) and one in planning for 1995 (Mighty Uncle[10]) reveals that fully half of the SNL personnel who participated in these tests have left Sandia. Of those who remain, virtually all are doing work very different from what they were doing in 1992. And of that remaining half, fully fifty percent will be eligible for retirement in the next five years.

We estimate that for the next five years, SNL may be able to conduct an UG/NWET, using experienced personnel as mentors. However, that capability will degrade in the years following. Moreover, since our time and budget estimates were based on the assumption that experienced personnel would be doing the work, our estimates are probably very optimistic. Beyond the five-year horizon, any effort to conduct an UG/NWET would essentially be "starting over." In addition to the loss of experienced personnel, we think that two additional factors contribute to this: (1) radically changed data acquisition technology and (2) poor documentation and archival of the way in which UG/NWETs were conducted.

3. ORGANIZATION OF THE REMAINDER OF THIS REPORT

In the section immediately following this one, we present the slides and notes for briefing that supports the foregoing conclusions. However, in preparing the briefing, we amassed a substantial amount of information about each of the five tests and the field engineering support required to field them. In the interest of completeness, and in the hope that these results will have lasting utility, we have included our notes from these six panels in Appendices A through F. During each of the panel meetings, one of us (TMB) led the meeting, while the other (DHZ) recorded the proceedings. After we cleaned the notes up and turned them into Microsoft Word® documents, they were forwarded to the subject matter experts (SMEs) on the panels to be reviewed for accuracy and completeness. Notes were also often reviewed by other SMEs who were unable to participate in the specific panels; thus, we believe that the notes are about as complete and accurate as possible. Appendix F discusses the manner in which we costed the data acquisition equipment required for the test along with other costs related to Field Engineering, and also discusses the way in which we converted FTEs into dollars.

Following the "Annotated Briefing" section and preceding the Appendices, we will close with a section that expands upon some observations that were not touched on in detail in the briefing, made during the course of this study, on SNLs' capacity to field an underground nuclear weapons effects test.

4. AN ESTIMATE OF SANDIA RESOURCES FOR UNDERGROUND NUCLEAR WEAPONS EFFECTS TESTING: AN ANNOTATED BRIEFING

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An Estimate of Sandia Resources for Underground Nuclear Weapons Effects Testing (UG/NWET)

Tom Bomber

David Zeuch

October 2002

Sandia National Laboratories

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This study was requested by members of the Program Directors Leadership Team (PDLT) and conducted by personnel in SNL Center 9800, Nuclear Weapons Program Integration and Studies. The study addresses Sandia's resource requirements to support an Underground Nuclear Weapons Effects Test (UG/NWET).

Outline

- Background
- Charter
  - Purpose
  - Study Contacts
- Methodology
- Test Selection
- Test Resources
- Summary of Test Costs, Schedule, & Personnel
- Experienced Staff Issues
- Overall Assessment

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The briefing will follow the outline on this chart. A brief background for the study will be presented, followed by a discussion of the charter. Next, is a section explaining the method used for the analysis. The remaining sections deal with the technical aspects of the study, ending with an overall assessment of Sandia's capability to support underground nuclear weapons effects testing.

Background

- Federal administration expressed an interest in increasing UGT readiness
- Perceived potential for additional funding
- Historical and current SNL ties to NTS:
  - Fire Sets and NGs
  - On-site department
  - Involvement in radiation and containment measurements on previous tests
  - Fielded nuclear weapons effects experiments

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The U.S. Government under the current administration has expressed concern about our ability to resume underground nuclear testing (UGT), and has recommended that the time required to resume testing be reduced. This interest in reducing the test preparation time will require an increase in test readiness funding. However, it is unclear who will receive such funding and if it indeed exists. Currently SNL is receiving some test readiness funds to support the development of a field-test neutron generator. SNL has historically supported UGTs by providing the device fire sets and field-test neutron generators. SNL once had a significant on-site presence at the Nevada Test Site (NTS) in support of UGTs, and was also involved in providing general support for containment measurements and tunnel radiation diagnostics. Finally, Sandia once was also a major player in fielding it own nuclear weapons effects experiments.

Therefore any change in the status of UGT is of concern to SNL.

Two Basic Types of UGTs

- **Weapon Development/Performance Tests**
  - **Generally in vertical shafts for reduced cost of containment**
  - **Focus is on the physics labs**
  - **SNL provides only NG and A&F support and Containment/Seismic Data**
- **Nuclear Weapons Effects Tests**
  - **Generally in horizontal tunnels (Horizontal Line-of-Sight Test)**
  - **Focus is on material, component, and system effects**
  - **SNL has been a major player in the past**
- **Current DOE readiness efforts address weapon performance testing only**

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It is important to note that two basic types of underground tests were done at NTS. First, there were weapon development and performance tests. The focus of these tests was the performance of the device itself and therefore these tests were primarily the work of the physics labs. These tests were generally conducted in vertical shafts for reduced cost of containment. SNL provided the more limited support discussed earlier, arming and firing, and field-test neutron generators.

The second type was nuclear weapons effects testing (NWET). These tests were usually conducted in horizontal tunnels. The focus of these tests was not the device but, rather, on the performance of nuclear and non-nuclear components during and after exposure to hostile radiation environments. In fact, it was extremely important to these tests to have a well-characterized device, because the objective of these tests was to determine the effects of nuclear radiation on various materials, components, and systems. SNL, the armed services and various defense contractors have been the major players in this arena.

SNL provided specific services under contract to the Defense Nuclear Agency for this type of test, including containment and radiation environment diagnostics, seismic measurements and special fast-acting closures. However, SNL also performed its own radiation effects experiments on components and materials of its own design and/or manufacture, and fielded "at-the-experiment" radiation diagnostics for these experiments, as well.

It important to note that the current DOE interest in test readiness really only relates to nuclear weapons *performance* testing.

Official Position on UG/NWET

- DTRA hosted a meeting in November 2001 on UG/NWET
- Reviewed/discussed official positions on:
  - Instrumentation
  - Devices (Well-Characterized Nuclear Source)

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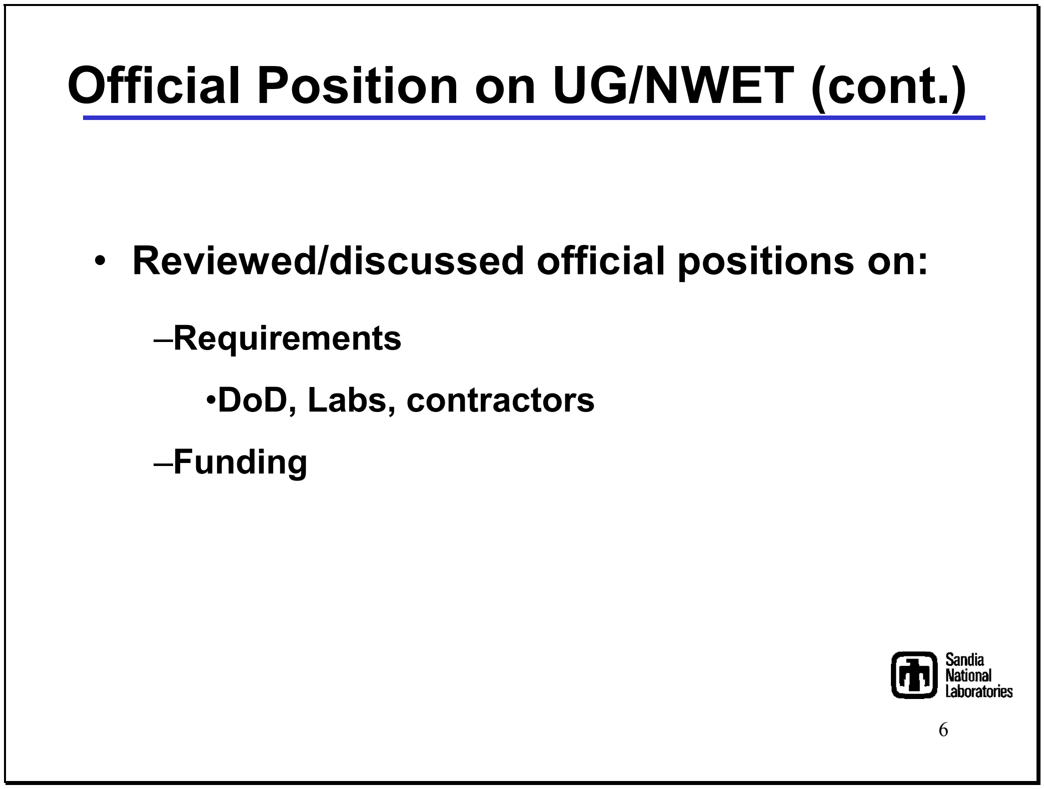
In order to address the issues of nuclear weapons effects testing, the Defense Threat Reduction Agency (DTRA) hosted a meeting in November 2001 on Underground Nuclear Weapons Effects Testing (UG/NWET). At this meeting the key players (DoD, test support contractors, system contractors, and the three national labs) in UG/NWET discussed the critical issues relating to UGT readiness.

The official position on instrumentation to support an UG/NWET was that there currently exists sufficient (mothballed) instrumentation (this includes cables) to support a typical test (about 2500 to 3000 signals). There is a line-of-sight (LOS) pipe in the P-tunnel complex and there are also some closures available. However, there were many at the meeting who did not agree that the instrumentation was adequate, because many of the instruments are no longer supported by their vendors and there has not been a complete evaluation of the instrumentation since it was stored in the early-to-mid 1990s.

Another critical issue is that there are no well-characterized nuclear devices available for the tests. A device with a predictable radiation spectrum was absolutely essential to the success of an UG/NWET, and substantial effort went into designing, building and testing a family of such devices that could simulate "hot," "warm" or "cold" X-ray environments. And even "well-characterized" devices showed sufficient variability that a substantial investment was made in radiation diagnostics to be certain exactly what the radiation environment was during a particular test.

From the meeting, it became clear that even developing a characterized device from existing drawings would be a major effort for the physics labs. Although drawings *may* exist for some of the well-characterized sources that were used for UG/NWET in the past, there is apparently no tooling available at LANL or LLNL with which to build them anymore.



Once built, at least one test would be required to characterize the device. P. Raglin (Dept. 9721) suggested that it might be possible to build several devices identical to one used in the past. If the test of one device from that batch showed that the yield and spectrum were within the previously measured range, it should probably be safe to assume that the remainder was "well-characterized."

Most importantly, however, no real testing requirements were identified at the meeting. The DoD representative (Mr. Fred Celec, Deputy Assistant to the Secretary of Defense for Nuclear Matters) stated that he didn't believe there would *ever* be a separate "effects test" again and that we (the labs) need to be ready to "piggy back" if there ever should be a performance test. At the meeting the Sandia representatives stated that "piggy backing" on a performance test was not an option for Sandia. Yield and radiation outputs from our current weapons are not consistent with the stockpile-to-target-sequence (STS) requirements that drive the nuclear hardness design requirements. All three nuclear labs stated that they had no urgent test requirements at this time, nor did the defense system contactors who attended the meeting.

Finally there was no established funding line for effects test readiness, although DTRA was attempting to get a $5M wedge in the budget for the out-years. Since the time of that meeting, Paul Raglin (personal communication) has advised us that DTRA has received $5M per year for the next five years for "test readiness," but it is unclear how DTRA will spend this money.

While there were some presentations speculating on potential—yet unconfirmed—weapons effects, the general conclusion of the meeting was that there was little or no official support for the resumption of underground nuclear weapons effects testing at this time.

Chartered by PDLT in Sept., 2001

- **Responding to a spate of official interest in reduction of UGT readiness timelines, the PDLT decided to conduct a study**
- **PDLT members thought it would be prudent for SNL to be able to answer the following questions:**
  - **What experiments would we want to do and why?**
  - **What would it cost?**
  - **How long would it take to field the experiments?**

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However, responding to the recent interest in general nuclear test readiness, some members of the PDLT thought it would be prudent for SNL to have an understanding of the resources required should we be asked about our readiness for UG/NWET.

At the meeting in which this study was chartered, the PDLT members agreed on three questions that they would like to be prepared to answer. The first had to do with why we might do such a test. That is, what experiments would we want to do and why? The second question deals with the resources required to support such testing and this comes down to costs. The final question was directed at understanding our state of readiness. How long would it take us to get ready to conduct the NWETs? To establish the context for this study, the direction given the study team was to assume that a series of a few NWETs was to be conducted.

Study Contacts (to date)

- Bill Barrett
- Brett Bedeaux
- Dave Beutler
- Jerry Chael
- Richard Damerow
- Frank Dean (R)
- Ed Duckett
- John Dudley (AWE)
- Craig Furry
- Ivars Gals
- Toby Garcia
- Ken Glibert (R)
- Fred Hartman
- Ron Hartwig
- Tom Henderickson
- Jacque Hohlfelder (R)
- Roy Holt
- Bill Kluesner
- Roy LeBlanc (R)
- Jim Lee
- George Novotny
- Paul Raglin
- Ken Reil
- Bryon Ristvet (DTRA)
- Fritz Roessler (DTRA)
- Charlie Sandoval
- Gary Scrivner
- Pat Sena
- Rod Shear
- Robert Stiers
- Bill Tedeschi
- Dave Thomson
- Rich Westfall
- Barton Wohl

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The personnel listed on this chart provided us with the detailed information that we present in the remainder of the briefing. These individuals represent the majority of SNLs' collective corporate memory in UG/NWETs. They helped us define the specific tests, identify the resources required to support the tests and made their best estimate at the timelines based on their prior experience with UG testing. Our thanks go out to these individuals for their enthusiastic support for this effort. We used their inputs to structure answers to the three questions, however any errors in interpreting and using their data rest with the authors.

Affiliations of non-Sandians are indicated in parentheses after their names. Retired Sandians are indicated by a red "R" in parentheses following their names.

Assumptions and Scope

- **A series of a few UG/NWETs would become possible or necessary**
- **Support beyond SNLs' immediate experiments (device, radiation diagnostics, containment measurements, etc.) would be provided by others**
- **Resource requirements will be assessed by focusing on one "typical" test**
  - **The experiments in this "typical"test would be mission-relevant**
  - **The experiments would be representative of those done by SNL in the past in terms of type and range of difficulty**
  - **Goal was to stress all parts of the test support structure with the example experiments**

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In order to provide reasonable answers to the questions posed by the PDLT, it was necessary to make some assumptions about definitions and scope. The first assumption was that this test would be part of a series of tests and not a one-time, crash program. The other important assumption is that all the support beyond SNLs' immediate experimental needs, such as the tunnel, LOS pipe, device, basic radiation measurements, etc., would be provided by others (*e.g.,* DTRA) as was the case in the past. This effort is focused on the experimental resources and timelines for Sandia only.

We next defined a "typical" test which could be used to estimate resources and timelines. A typical test was defined as one that includes a set of experiments that are representative of the types conducted in the past, and which span the full range of experimental difficulty encountered in past testing. Looking beyond the past and present, we also hoped that the experiments might be representative of the types of tests expected to be important to the systems design community in the future. The immediate objective of the "typical" test was to exercise all parts of the test support structure to identify any potential weaknesses. However, to have credibility we wanted the experiments to be mission-relevant, as well.

Experiment Selection Criteria

- **Experiments must be mission-relevant**
  - **Guidance obtained from Pat Sena's June '01 memo on potentially useful tests if UG effects testing were to be reinstated**
- **Convened a panel of experts to down-select to *five* specific experiments from this memorandum**
  - **Confirmed mission-relevance**
  - **Developed high-level experiment definitions & objectives**
  - **Referred us to additional ~~victims~~ experts who could provide detailed definition of experimental resources in five subsequent SME panel meetings**
- **Field Engineering at NTS was costed as a separate activity after experiments were defined (i.e., a sixth panel)**

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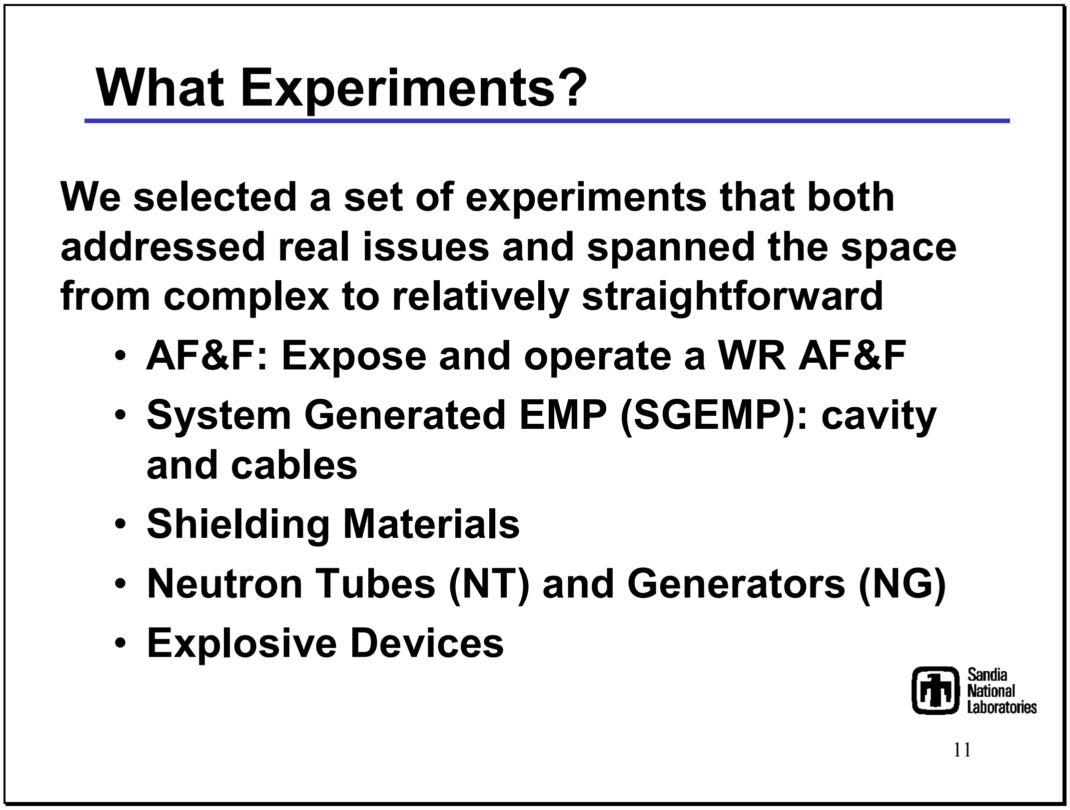
As the result of a request from Paul Raglin to Pat Sena (SNL Dept. 2115), at the outset of this study we had access to a fairly long list of mission-relevant experimental areas from which to choose. Essentially, Pat was asked to provide a list of high-priority experimental areas that SNL would like to test in *if* the opportunity were provided to conduct UG/NWETs. The memo provided by Pat was the result of a survey of the key weapons system personnel and summarized a list of mission-relevant, high-level issues and experimental areas.

We convened a panel of experts in weapon systems and weapon effect testing to select from this memorandum five specific experiments to be included in our "typical" test. This panel reviewed the experimental areas for mission-relevance and developed high-level definitions and objectives for each experiment selected.

Based on these definitions and objectives, we then assembled subject matter experts (SMEs) in each of the selected experimental areas. Through a series of additional meetings with these experts, very detailed experiment definitions and estimates of required resources were developed. The results of these meetings provided a good estimate for the direct experiment support. What remained was to obtain an estimate of the Field Engineering support needed for data acquisition, signal conditioning, and recording.

This information was obtained in the sixth panel meeting with SNL SMEs at NTS.



This chart lists the five experiments chosen for this study. It was felt that these experiments were mission-relevant experiments, and spanned the support space from relatively straightforward to complex. The next six charts address some of the detail in the experimental definition process. The first of these charts addresses an issue relevant to all the experiments, which is the selection of the number of samples to be tested. The five charts following describe the five experiments in some detail. A more complete discussion of each of the experiments can be found in Appendices A through E.

Experimental Uncertainties

- Number of experimental samples is driven by four factors
  - Uncertainty in the radiation level provided by the nuclear device
  - Statistical difference in the response of the samples due to materials, radiation incident angle, and sample orientations
  - Number of orientations that need to be tested
  - Size and Cost of the samples
- The first three factors tend to increase the number of samples and the fourth tends to moderate the practical number of samples

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One of the factors that determines the size of the experimental resource requirements is the number of experimental samples that need to be tested. That is influenced by four factors. One is the uncertainty in the radiation level provided by the device. To account for this uncertainty the number of samples is increased to attempt to bracket the desired level by filtering. A second uncertainty which affects the number of samples is statistical uncertainty in the response of the samples themselves, and the impact of geometry, for example, orientation of the sample to the radiation field and the incident angle of the radiation on the sample surface. A third issue can arise when a complex assembly such as an AF&F, RB or neutron generator needs to be tested in multiple orientations to fully assess its survivability or functionality. In this eventuality, multiple units need to be tested in multiple orientations relative to the incident radiation beam.

These first three factors tend to increase the number of samples required in the experiment. However, the fourth factor—which is the size and cost of the samples—tends to moderate the practical number of samples. There is a limited area available in the line-of-sight pipe and the air scatter stations, and generally there is considerable competition for the space. This limits the number of large samples. Finally there is the cost of the samples, running from a simple coupon of material to a full AF&F, which will moderate the number of samples.

In the experiments presented here, all of these factors played a role in selecting the specific number of samples to test in each experiment.

AF&F: Expose and Operate a WR AF&F

- The objective of this type of test would be to obtain data to support the qualification process or to test an existing system to get insights into the effects of aging at the system level.
- In this test four WR AF&Fs would be exposed and operated during and after the event.
  – With some modification to the AF&F's external housing it can be tested either using external power or by externally initiating the thermal batteries.
  – This would require "Testers" located some distance from the AF&F that would operate the system.
- This experiment would also stress the computational resources by requiring the definition and design of the appropriate exposure orientation, filtering and shielding.
- The most complex test would be the test of the AF&F in the radar fuzing mode.
  – We would want to have the system operating during exposure.

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The test of an AF&F would either be a qualification test for a new AF&F design or testing to investigate possible aging problems in an existing system. Full-up AF&F testing would require the operation of the AF&F test articles either after exposure or during exposure. Testing the AF&F system requires the use of a "tester." This is a system which provides the necessary environment for the AF&F to operate as if it were in-flight. In this study, we encountered some confusion between the terms "simulator" and "tester". The terms "testers" and "simulators" are often used interchangeably when referring to a system that provides inputs to the test article to simulate its operational environment or a system that provides outputs simulating those of the test article to confirm operation of the data acquisition system. Generally the context will indicate the intended use. Operating the AF&F in the radar fuzing mode is probably the most difficult tester problem.

In the pre-test activities, one of the most challenging tasks would be the calculations required to determine the appropriate exposure levels and orientations to properly stress the AF&F system.

While the goal would be to have the most WR-like AF&F possible, some modification of the AF&F external housing would be required. Again, this must be done with care to insure that the experiment is not compromised.

We assumed that no explosive components would be used. The test would be done in an air scatter station with filtering to obtain the appropriate radiation levels. The test would include 4 Gaffs and 4 testers to drive the specimens from a distance of up to 300 feet.

Additional details about this experiment may be found in Appendix A.

System Generated EMP: Cavity and Cables

Conduct a suite of cable and cavity SGEMP measurements to support validation of computational models currently being developed to calculate cable response, SGEMP currents in cables.

- **Cables: The objective is to conduct a SGEMP test on WR cables. The direct-drive cable SGEMP experiment is conducted in an elongated test cassette in the LOS pipe. The experiment will consist of multiple cables to cover the threat spectrum and experimental uncertainties**
- **Cavity: The test needs to be conducted in the LOS pipe. The experiment will be done on full-up RBs including the RB aft frustum unit. Cavity test items need to be representative of different cavity dimensions and different air pressures. The number of samples was selected to cover experimental uncertainty**

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In constructing the System-Generated Electromagnetic Pulse (SGEMP) tests we made the assumption that the computational models would have been completed and would be used to evaluate cable and cavity designs in an EMP environment. The objective of the test would be to validate the cable and cavity design guide models. Regarding the cable-SGEMP experiments, additional assumptions were that WR-like cables would be available for testing, and that three types of cables would be tested. These would be NG cables, pre-set AF&F cables and a generic cable. These cables would be tested at various radiation levels and orientations.

The assumption for cavity testing was that it would essentially be an “Admiral’s Test” involving a full-up re-entry body (RB). Here, we made the assumption that we have a robust above-ground test (AGT) capability for cavity testing, but that we just can’t get threat levels over full systems.

We further assumed that WR-like RB hardware could be made available, including NGs and Gas Bottles. The test would require three such RBs.

The assumption concerning a robust AGT and modeling capability for cavity SGEMP was vigorously discussed. It was argued that some very simple cavity shapes along with—or instead of—the RBs, should be included in order to have comparatively straightforward experimental results against which to test the computational models. Cavity shapes within a WR-like RB may be too complex to try to model in the first of a series of UG/NWETs. We did not include these experiments in our representative test, but additional thought should be given to this problem should testing resume. A more complete discussion of the issue can be found in Appendix B.

Shielding Materials

- **A suite of shielding material experiments addressing thermomechanical shock (TMS), thermostructural response (TSR) and differential thermal expansion (DTE).**
- **This test is focused on model validation for RB/RV, AF&F and neutron generator shielding material. Material samples would be 1-dimensional (1D) and 3-dimensional (3D).**
- **Samples would be exposed at different levels of radiation to bracket damage levels.**
- **The results would be used for model input parameters, validation of computational models, and correlation with AGT experiments.**

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This experiment assumes that we continue to have a robust computational and AGT program in the area of shielding materials. Under this assumption the UGT could be a validation test for shielding material evaluation models, or intended to collect material properties need for computational design models.

The test specimens will include coupons, rings, and frusta. The coupons will be used for thermomechanical shock (TMS) effects testing, the rings for thermostructural response (TSR) effects testing and the frusta for combined effects. Ten materials would be tested in coupons, five materials in rings, and three materials in frusta.

These material and configuration types will be tested at a variety of radiation levels and orientations. These variations are selected to bracket the uncertainty in damage levels and uncertainty in actual exposure levels.

This experiment is discussed further in Appendix C.

Neutron Tubes (NT) and Generators (NG)

- **This experiment would involve the exposure of a series of NTs and NGs to several x-ray dose levels in different materials. The objective is to assess the impact on the NT/NG by conducting both passive and active experiments.**
- **The passive experiments involve returning exposed NTs and NGs to the lab where some are operated to measure output performance and others are dissected and inspected.**
- **The active experiments involve firing the NG in the tunnel just after exposure and just before the ground shock.**
  - **"Active" NGs that fail to fire would be returned to the lab for inspection.**

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This experiment is a generic NG experiment. This is the type of test that would be done for qualification as well as for validating design guidelines. In this test a series of 54 NGs will be tested passively or actively.

For the passive generator test the specimens will be exposed to various levels of radiation and at various orientations. These generators will then be recovered and sent to the lab either to be fired and have their output performance measured, or dissected to inspect for any damage.

The active test specimens will actually be fired in the tunnel, *after* the radiation exposure but *before* the ground shock arrives. Electrical and neutron outputs will be measured during firing. These generators will also be exposed to various levels of radiation and at various orientations. This type of testing will require the design and development of a six-sided explosive containment specimen holder. It will also require development of a neutron detection system, which can acquire the generator output signal in the incredibly noisy tunnel environment. Any active samples that failed to fire would also be recovered and returned to lab for dissection and analysis.

Details about the costing of this experiment can be found in Appendix D.

Explosive and Pyrotechnic Devices

- **These types of tests would be required if there are any changes to the explosive materials' manufacturing process or if new containment or explosive materials are introduced.**
- **This experiment would involve the test of several explosive timers, actuators, detonators, and isolators. The purpose of these experiments is to measure the damage to explosive material from the interaction of the radiation and the explosive containment materials, and to determine the deflagration levels of the various explosive materials.**
- **60 to 80 samples at each of two or three radiation levels and at least two orientations per level, should cover the experimental uncertainties.**

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This test is based on the assumption that we have had to change the manufacturing process for—or the design of—the explosive and/or pyrotechnic components. In this case there would be both active and passive tests. The objective is to detect any damage to the explosive material from interactions with the radiation and/or explosive device containment materials. For new explosive materials the deflagration levels are also an important property to verify.

In the passive test the samples would be exposed to various levels of radiation and at various orientations. The samples would be recovered after the test and inspected and analyzed. Then some of the passively tested samples would be operated and their outputs measured.

The active tests, which involve firing the items in the tunnel, require the development of explosive containment sample holders. Outputs from the various devices would be measured during exposure, and any devices that failed to fire would be returned to the laboratory for inspection and analysis.

The experiment is designed to have the samples exposed to various radiation levels to account for the uncertainty of the actual level attained in the tunnel.

More details about this experiment are presented in Appendix E.

Field Engineering at NTS

- **All new instrumentation would be required**
  - **Fiber optic cable would be used to bring the signals up from the tunnel**
    - **Recording would be done above ground in Building 12-909**
    - **Primary signal conditioning would be done in the tunnel**
    - **LF was defined as DC to 3 MHz, Mid Freq. 3MHz to 100MHz and HF greater than 100 MHz**
  - **Resources for the experiment cassette development and production are covered under the individual experiments**

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In addition to the individual experiments, another source of SNL resource consumption on UGTs is the Field Engineering effort. The field engineering picks up at the experimental cassette outputs and inputs. This support covers the signal conditioning and interconnect cables from the cassettes to the main cabling in the tunnel complex provided by DTRA. This effort is significantly different from the experimental effort and it was treated separately.

Field engineering includes primarily data acquisition, recording, and test control and monitoring type activities. It also included some investments in above-ground buildings used for data acquisition and recording, and test monitoring and control.

An assumption was made that this UG/NWET would require all new instrumentation for data acquisition and recording, because of the major changes in technology in this area over the past decade. This assumption is confirmed by our experience supporting the sub-critical experiments.

This experience also indicates that for our test, the signals would be brought out of the tunnel on fiber optical cables and whenever possible the recording would be done above ground. However, signal conditioning would be done in the tunnel alcoves. The signals were divided into three frequency ranges, because there are distinct instrumentation costs associated with conditioning and recording each frequency. As part of the costing exercise, we actually reduced each signal to a “cost-per-channel,” based on frequency, that included conditioning and recording equipment.

In our costing methodology all the experimental cassette development and production is accomplished under the individual experimental support activities.

Details of the definition and costing of this activity are included in Appendix F.

Field Engineering at NTS (cont.)

- **There would be three recording/signal conditioning alcoves and one air scatter station**
- **The installation phase would be 8 months**
- **The alcove lead engineer and the lead techs are SNL personnel**
  - **The majority of additional on-site support will come from BN**

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Field engineering picks up at the experimental cassette outputs and inputs. This support covers the signal conditioning and interconnect cables from the cassettes to the main cabling in the tunnel complex provided by DTRA

It was assumed that supporting the test as defined here would require three recording alcoves and one air scatter station. The high intensity phase of test support is the installation phase, which will last 8 months.

Except for key SNL personnel (the alcove lead engineer and technicians) most of the on-site support (field construction and technical support) would be contract personnel from Bechtel Nevada (BN). The cost of the contract personnel is included in our estimate.

What Cost?

- **Assumptions**
  - **DTRA would provide device, tunnel, LOS pipe,sieves, closures, infrastructure support, etc.**
  - **Only SNL experimental costs considered**
  - **This test would be one of a short series of tests**
- **Met with experts in the specific experimental areas to estimate the required resources.**
  - **Divided each experiment into individual activities for estimating purposes**
- **Also met with experts to estimate the resources required for Field Engineering support**
- **Where possible had estimates reviewed by additional experts**

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The way we estimated cost was to collect information from the experts on required resources and convert them into dollars.

Our assumption for costing was that DTRA would—as they have in the past—provide the device, tunnel, LOS pipe, infrastructure support, etc. Therefore our costs only include SNL experimental costs and experiment-specific, field engineering costs.

In our meeting with the subject matter experts for each of the experiments, we divided the experimental support into individual activities and had the experts provide resource estimates for each of the activities. We used the same technique for the field engineering support, but the activities were very different for this support.

Once we had collected the resource requirements for each of the experiments, we attempted to find additional individuals with experience in that specific area to review the estimates. This provided a good check and in some cases identified additional resource requirements that had initially been overlooked.

The final step was to convert the resources, personnel, and equipment into dollars.

Definition of Experimental Resources

- **Estimates of experimental detail**
  - **Assumptions**
  - **Number of items/samples**
  - **Cost per item**
  - **Timeline to acquire**
- **Estimate to design and build filters, gauges, experimental cassettes with appropriate shock mountings, etc.,**
  - **Timeline,FTEs, ODCs**
- **Estimates of pre-test modeling and simulation work**
  - **Timeline, FTEs, ODCs**

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These two charts itemize the specific activities used to estimate resources. The process began with a list of assumptions and description of the specific experiment. The definition included the number of experimental items/samples and information on the cost-per-item and the time to acquire the required number of specimens.

The next activity focused on the equipment necessary to actually field the experiment. This included the specimen holders (cassettes), the various filters needed for the desired level of exposure for the samples, and the diagnostic equipment required like calorimeters, strain gauges, etc. For each of the activities we collected estimates of the time required to complete the activity, the number of FTEs (fully loaded Staff and Tech), and all the other direct charges (ODCs) for equipment, material, travel, *etc.*

The third activity was the pre-test modeling and simulation work that was required for each experiment. This could include model development and/or simply setting up existing models, running them and analyzing the predictions. For this category and the next (AGT Support- see next slide) only those efforts which were the direct result of supporting the UGT were counted. Work that would normally be done in these areas with or without a UGT was not counted. Several experiments did not require any pre-test modeling and simulation, and/or AGT

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Definition of Experimental Resources (cont'd)

- **Estimate of AGT pre-test work**
  - **Timeline, FTEs, ODCs**
- **Estimates of down-hole experimental "testers/simulators"**
  - **Timeline, FTEs, ODCs**
- **Estimates of data acquisition requirements**
  - **Number of signals to be recorded**
  - **Signal bandwidth**
  - **Recording time/length**
  - **Required signal conditioning**
- **Estimates of instrumentation installation, fielding and checkout**
  - **Timeline, FTEs, ODCs**
- **Estimates of experiment recovery**
  - **Timeline, FTEs, ODCs**
- **Estimates of post-test analysis**
  - **Timeline, FTEs, ODCs**

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Then estimates were made for any AGT pre-test work required to prepare us for the selection of the appropriate damage thresholds, radiation exposure levels, and orientations. Tests would also be performed to evaluate the experimental set-up to confirm that there were no unexpected effects of the radiation environment on test measurements or data acquisition.

The fifth activity covered the design and fabrication of the testers and simulators. It is worth reiterating that "simulators" provide dummy output signals *identical* to those that are expected to be sent by the measuring devices at the experiment. They are used to validate instrumentation and recording set-up. "Testers" provide a simulated working environment for the item that is the subject of the experiment. In the case of an AF&F, testers provide simulated submarine or silo signals to the AF&F. They also provide the simulated signals the missile provides to the AF&F during powered flight and separation.

The sixth activity is different from the others. In this activity, we gathered data that was useful in estimating the resources consumed by the Field Engineering activity, most importantly the number of signals to be recorded, and their frequency ranges.

As the test time approaches, the installation activity is directed at the support required in fielding the experiments. This activity includes the physical installation of the cassettes, filters, shields, specimens, testers, and simulators. It also includes the support required for the rigorous pre-test checkouts and simulated countdowns.

The last two activities take place after the test, and they include the physical recovery of the experiments and experimental equipment, and the post-test analysis and report preparation.

The next two charts provide an example of the level of detail that was used in estimating resources for a few of these activities.

Example of Detailed Resource Estimates

NG Experiment **:Estimate to design and build filters, gauges, experimental holder etc.:**

Timeline: (All completions 6 months before test)

1) 1 yr to design & fabricate and test explosive containers (15+ test boxes) assuming 2 NGAs per box.
2) 1 month to design & fabricate filters located at each experimental box.
3) 2 yrs to design & fabricate triggers (2 Compton diodes for redundancy) used to initiate the fire signal to the fireset that fires the generators. The diodes are located somewhere in the LOS pipe.
4) 24 months to design & obtain diagnostics (Au calorimeters for X-rays, 1-2 per box) and neutron detectors (1 per box, located in vacuum but well shielded and stubbed out to the side).

FTEs: 5.5

ODCs: $ 4M

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The first example is from the Neutron Generator experiment, and covers the activity under which filters, gauges, experimental holders, *etc.*, are designed and built. This is an example of the detail we gathered from the subject matter experts. In their opinion this task would take a minimum of 2 years to complete, and would require 5.5 FTEs and $4M in other direct charges (ODCs) for equipment and materials.

The complete details for the resource estimates for all the experiments can be found in Appendices A through E.

Example of detail Resource Estimates (cont.)

Shielding Materials Experiment:**Estimate of pre test modeling and simulation work required**

Assumptions (models, runs, objectives etc.)

Codes and material models are being worked on now, for example TMS models, spall models, TSR model, especially for porous materials. The assumption is these models will have been completed before UGT testing.

Timeline: Four years running in parallel with the last four years of the test item acquisition.

FTEs: 3

ODCs: $50K/year for total of $200K

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The next example comes from the Shielding Materials experiment. This is the "pre-test modeling and simulation" activity. This activity would take four years and require 3 FTEs and $50K per year in other direct charges.

Example of detail Resource Estimates (cont.)

***AF&F Experiment:* Estimates of down hole experimental "simulators/testers"**

- **Assumptions (objectives, etc.,):** MUX simulator is not required as AF&F can be used for dry runs. End-event signals were simulated with a separate box. Testers are needed.
- **Timeline:** At least two years to design and build, with testers available for checkout in the AGT series.
- **FTEs:** 4 FTEs.

  ODCs: $250k each for 5 testers that include radar simulation, for a total of $1.25M (current dollars).

***Explosive Devices:* Estimates of down hole experimental "testers"**

- **Assumptions (objectives, etc.,):** Testers would be required. We would need something to generate the output of the isolator CVT, detonators, actuators and timers. The detonator, actuator and timer would require a resistive load with monitor points, and a pulse generator would be required. A special generator would be built for this purpose. A single box would work for multiple devices., maybe eight black boxes total.
- **Timeline:** Three months would be needed to design, build and test the "testers."
- **FTEs:** 0.1 FTE

  ODCs: $6K total would be needed for parts for black boxes.

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These two examples are from the "AF&F" and "Explosive Components" experiments, respectively. They cover the activity under which down-hole simulators and testers are developed.

We have discussed earlier the importance of— and differences between— "simulators" and "testers" (p.36). However, it bears mentioning again that their design, fabrication and testing was something of an art form in and of itself. Many of the expected signals that the simulators were intended to mimic were quite complex, so the design of a simulator was not necessarily a straightforward problem. And accurate simulation was needed to ensure that recording systems were up to the task. "Testers" were even more complex.

Definition of Field Engineering at NTS

- **Design Phase**
  - **Project Management Group**
    - **Timeline, FTEs, ODCs**
  - **Data Systems Design**
    - **Timeline, FTEs, ODCs**
  - **General Support (e.g., Drafting)**
    - **Timeline, FTEs, ODCs**
  - **Capital Investment (H/W, Facilities)**
    - **Timeline, FTEs, ODCs**
- **Installation Phase**
  - **Underground (General Support, Cable Crew)**
    - **Timeline, FTEs, ODCs**
  - **Aboveground (Recording, Admin., ES&H, QA, Data Base, Monitor & Command, CP1 Crew)**
    - **Timeline, FTES, ODCs**
- **Recovery**
  - **Recovery team**
    - **Timeline, FTEs, ODCs**

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The activities defining the Field Engineering support are shown on this chart. There are basically three phases of the support: design, installation, and recovery. The design phase is the long-term, lower-level of support which includes some capital investments at the site.

The second phase is installation and there are two sub-elements to this phase. The first sub-element is the underground support, which includes cable-building, hookup, and testing; mechanical work; and general support in the tunnel.

The second sub-element, above-ground support, includes surface work for data collection and test monitoring and control. The above-ground support also includes administrative, ES&H, and quality assurance support.

The final activity is recovery support, which includes retrieval of instrumentation from underground, as well as recovery of experimental specimens that are to be examined and/or tested in the laboratory.

Complete details for this activity can be found in Appendix F.

What Cost?

Experiment Cost (K$)	ODCs		Labor		Total	
	High	Low	High	Low	High	Low
SGEMP Experiments	$3,680	$3,270	$1,750	$1,200	$5,430	$4,470
AF&F Experiment	$5,338	$3,681	$1,910	$1,706	$7,248	$5,388
Shield Materials Experiments	$8,250	$8,250	$6,550	$4,600	$14,800	$12,750
NGA Experiment	$8,565	$5,541	$2,981	$2,731	$11,546	$8,272
Explosive Devices Experiment	$348	$300	$1,029	$954	$1,377	$1,254
Field Engineering	$22,046	$22,046	$21,358	$21,358	$43,441	$43,404
UGT Test Total	**$48,227**	**$43,088**	**$35,615**	**$32,549**	**$83,842**	**$75,537**

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This chart summarizes the results of the cost analysis. In some cases the SMEs could not agree on a specific level of resources required so they provided a range of resources that may be required and we preserved these ranges. This resulted in the High and Low estimates shown in the chart. The cost of support for this typical set of UG/NWET experiments ranges from 75 to 84 million dollars.

It needs to be pointed out that this expense would be spread out over the total life of the test, which could run for 5 or 6 years. If we assumed a uniform spend rate over 5 years (which is probably not anywhere near correct), the cost per year would be about $15M to $17M. However, if we were supporting three tests in different phases (which was typical in the past), then the average might be closer to correct for the three or about $45M to $51M per year, which, according to both anecdotal evidence and budgetary data was approximately our budget for UGTs in the early 90s.

Another fact to consider is that the majority of the ODCs in the Field Engineering activity is for new instrumentation and capital improvements. If, as we assumed initially for this study, there was a series of tests, than these costs would be shared by each of the tests. This is because the instrumentation could be reused for successive tests and the capital improvements are a one-time expense. Assuming that the $1.3M facility improvement cost and eighty percent of the $20M-plus instrumentation cost is for reusable instrumentation, then the cost for each of the following two tests might be reduced to a range of about $58M to $67M.

What Cost? (cont.)

Experiment Cost (K$)	ODCs		Labor		Total	
	High	Low	High	Low	High	Low
SGEMP Experiments	$3,680	$3,270	$1,750	$1,200	$5,430	$4,470
AF&F Experiment	$5,338	$3,681	$1,910	$1,706	$7,248	$5,388
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Field Engineering	$22,046	$22,046	$21,358	$21,358	$43,441	$43,404
UGT Test Total	$48,227	$43,088	$35,615	$32,549	$83,842	$75,537

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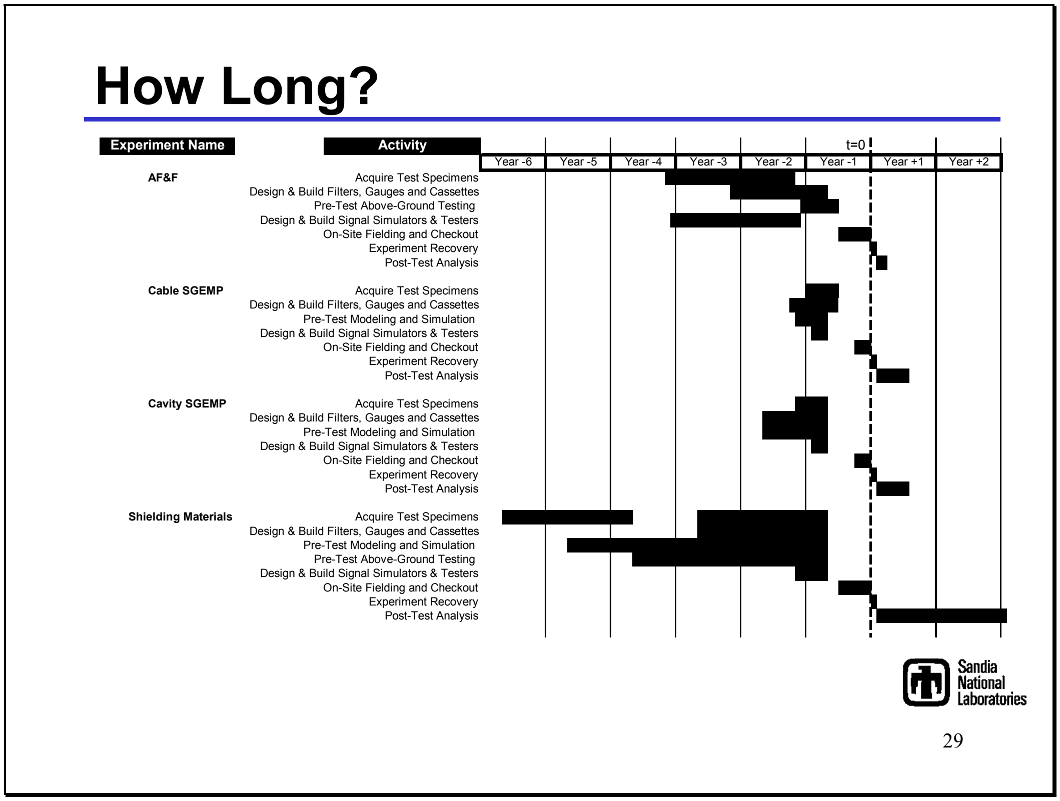
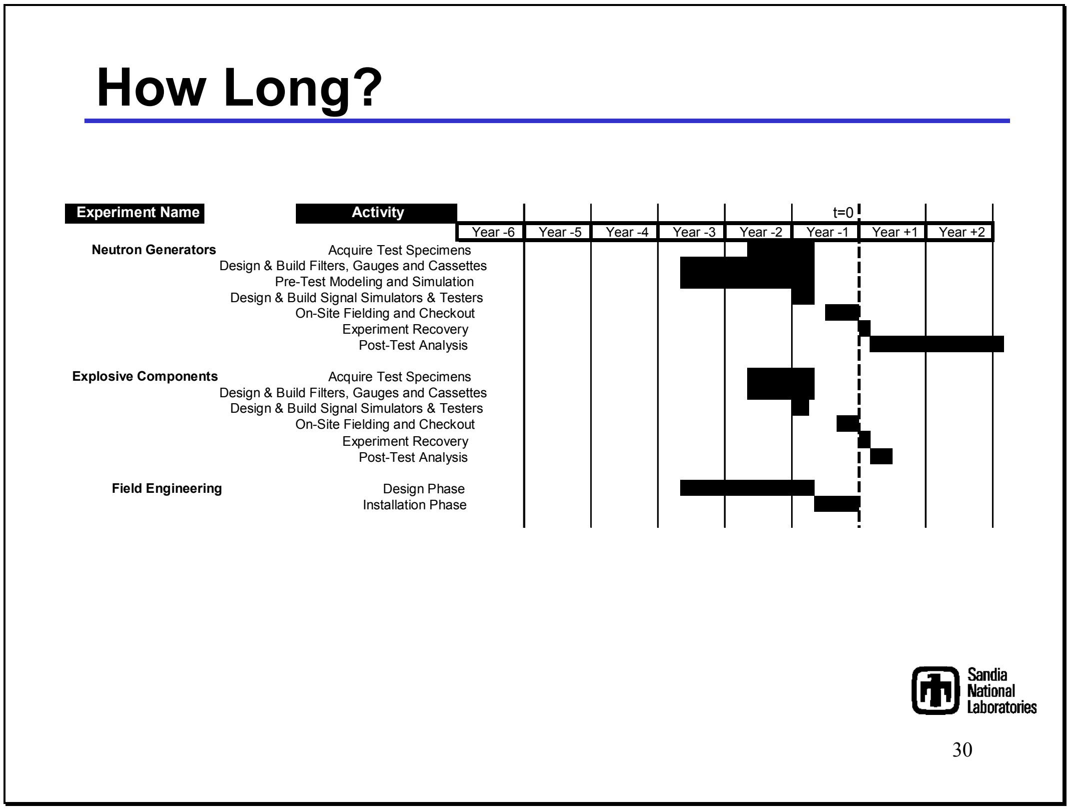
With these assumptions the cost of a series of three tests would range from a high of $84M for the first test and an average of $66M for the next two tests, for a total of $216 million at the high end to a low of approximately $180M.

These costs are estimates only, and surely we have inadvertently missed some resource requirements. However, we feel that we have the "80 percent solution" here. The actual test cost differences would be more affected by changes in the experiment definition and scope of this "typical" test than by any unaccounted-for resource requirements for the specific experiments in this "typical" test.



These next two charts show the timeline for SNL support of this "typical" UG/NWET. This chart shows the timelines for the AF&F, Cable and Cavity SGEMP, and Shielding Materials experiments.

This is an estimate of the timeline for the support required to execute this "typical" test. The total time is on the order of seven years. However, the bulk of the support requirements occur over about a 5-year period. More importantly, the SMEs providing us these estimates generally assumed the activities would be conducted by experienced personnel. Therefore, these timelines are in general optimistic, and they will only become more optimistic as time goes on.



This chart shows the timelines for the Neutron Generator and Explosive Components experiments, and the Field Engineering activities.

The timeline data shown in this and the preceding slide show that activities supporting this test would be conducted over an eight year period from Year-6 to Year+2. However, the bulk of the activities are actually in Year-3 through the first six months of Year+1. Therefore, the majority of the test support activity would be concentrated over a 3-and-a-half year period.

Personnel

Personnel Requirements	Staff		Tech		Total	
	High	Low	High	Low	High	Low
SGEMP Experiments	6.1	6.1	1.5	1.5	7.6	7.6
AF&F Experiment	6.3	5.5	2.3	2.2	8.5	7.7
Shield Materials Experiments	21.1	13.6	8.5	8.0	29.6	21.6
NGA Experiment	9.6	8.6	3.9	3.9	13.5	12.5
Explosive Devices Experiment	3.2	2.9	1.6	1.6	4.7	4.4
Field Engineering	48.2	48.2	62.1	62.1	110.5	110.3
Total Personnel	94.4	84.9	80.0	79.2	174.5	164.1

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This chart shows the level of effort required to support the "typical" test. The total FTEs are the estimates from the SMEs. We estimated the split of labor between Staff and Technologists, so it is not very accurate and is only intended to provide order-of-magnitude information.

SNL support for a typical test is around 170 FTEs. However, this level of effort is spread over the test's time line of 5 to 6 years. Using an argument similar to the one used on the cost data, the average annual level of effort to support a series of tests would be about 35 FTEs. In addition, a large fraction of the effort is the result of the Field Engineering activity. As we stated earlier, except for key SNL personnel much of this support would currently be provided by the site contractor, now Bechtel Nevada. This level of effort would be spread over a wide range of expertise and skills.

While this level of effort could have some impact on the other programs at the Labs, it would not be a major effect. **The real issue is finding personnel with the necessary experience, expertise, and skills.**

Issue: Experienced Personnel

Planned 1995

	Mighty Uncle	
	Then	Now
All	75	38
Mgr	7	1
Staff	35	19
Tech	30	18
Other	3	0

1992

	Hunters Trophy	
	Then	Now
All	84	46
Mgr	4	0
Staff	36	23
Tech	34	21
Other	10	2

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We conducted a simple analysis of the personnel involved in our two most recent UG/NWETs, Hunters Trophy (1992) and Mighty Uncle (planned for 1995 but never executed).

The results presented here show the number of the personnel still on-roll at Sandia. The data are organized by labor categories of the individuals at the time of the tests. A little more than half of the personnel working on these two tests are still on-roll at SNL, but many of the individuals who remain have been promoted (or stepped down from management) and others are now working in very different fields. We also looked at the status of those remaining and found that about half of the remaining personnel will be eligible for retirement in the next five years.

For perhaps the next five years, SNL has a large enough pool of experienced personnel to work with, and mentor, new personnel, and thereby be able to support an UGT. However, this team will not be as efficient as when testing was suspended. Subject matter experts were not asked to consider mentoring when making their estimates of time and number of staff. This makes the cost data optimistic and the timeline estimates presented even more optimistic.

In another five years it will almost be like starting over to support an UGT. Many of the early errors will surely be made again, since there is little documentation on how SNL supported the previous tests, and with the major changes in instrumentation, some of the experience of the past may not be that relevant.

Overall assessment

- **Requirements**
  - **There are no requirements for UG/NWET**
  - **There is no formal readiness program for NWET**
- **Resumption of effects testing would require considerable work in nuclear device development (up to three device tests)**
- **P- tunnel complex exists; however developing a new complex would cost approximately 450 million dollars**

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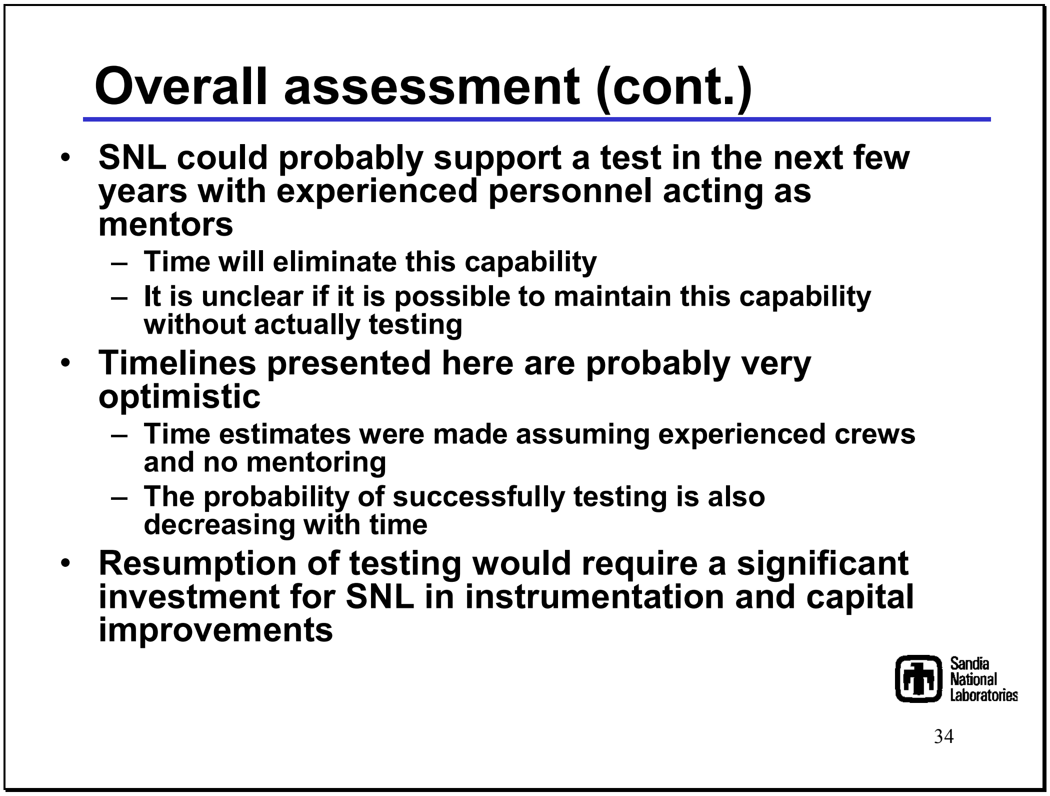
An overall assessment is presented in the next two slides.

There are currently no requirements for conducting an UG/NWET, and there is no formal program at DTRA or DOE to maintain readiness for such tests. All the readiness efforts are focused on weapon performance testing, *i.e.,* vertical shaft testing. Only a small portion of the readiness activities for performance testing would support effects testing in a horizontal tunnel. Some of the instrumentation work on the sub-critical testing would support effects testing.

Resumption of efficient effects testing would require significant effort in device development. There are no known devices available. While drawings do exist, no fabrication hardware is available. Moreover, rebuilding devices from old drawings would still require up to three device tests just to characterize the device output.

The P-tunnel complex currently exists and could be used for testing, however developing a new tunnel complex was estimated to cost DTRA approximately $450M.



SNL can support a NWET in the next few years with personnel who have prior experience acting as mentors. However, just the passage of time will eliminate this capability. It is unclear that there are any reasonable steps short of actually testing underground that SNL could take to maintain our expertise in supporting UG/NWET.

All our evidence indicates that the timelines presented here are very optimistic, because they were made without considering mentoring and using inexperienced personnel; as time goes by we will we lose more and more experienced personnel and the probability of a fully successful initial test decreases, and we are doomed to make all the same mistakes we did on the first tests. This conclusion is supported by the fact that good documentation on testing details is non-existent.

The first test would be expensive for SNL, because there is a need for a significant investments in new instrumentation and capital improvements on-site at NTS.

5. ADDITIONAL OBSERVATIONS AND CONCLUSIONS

At this point it is worth discussing some additional items, not covered in any detail in the briefing, that we have learned about the planning and execution of underground nuclear weapons effects tests. We think that these observations offer some additional insights into (1) the level of planning that was required for successful testing even at a time when our level of competence was high, and (2) some additional weaknesses associated with resumption of testing that will only increase with the passage of time. We will also point out some cost areas that were specifically excluded from our investigation, along with vanished capabilities.

During the years prior to adoption of the unilateral underground test moratorium, the Defense Nuclear Agency (DNA, now DTRA) planned its underground tests on a moving, five year-cycle. As each new test was announced, Sandia management in the directorate responsible for underground testing (variously named through time) would solicit input for weapons effects experiments. During the period from about D-5 years to D-2.5 years, these experiments would be reviewed, accepted, rejected or reworked and then prioritized in preparation for DNA calls for experiments at D-2.5 years.

Thus, some SNL work on a particular test could actually begin as much as 5 years prior to the event. In addition to work on particular experiments, Sandia also had ongoing efforts to develop new data acquisition capabilities, as well as radiation and containment diagnostics.

As an aside, according to the July 15, 1989 edition of the SNL telephone book, the (then) Director of Field Engineering (7100) had a division (the equivalent of a current department) dedicated to each of these activities. As remarked upon elsewhere, SNL provided radiation and containment diagnostics under contract to DNA for all UG/NWETs. In fact, DNA usually employed *three* contractors to evaluate the radiation environment in the LOS pipe so that a “vote” could be taken in the event of disagreement. However, SNL also believed that it was important to maintain its own radiation diagnostics capability in order to provide special types of measurements or triggers to its own experimenters. This would include the “in-the-cassette” diagnostics that we discuss later in this section (and in our notes), and the Compton diodes that trigger the active neutron generator experiment. Our subject matter experts are in agreement that both SNLs’ radiation diagnostics and containment capabilites have long since vanished.

At D-2 years, the first of a series of Program Officers Meetings would be held, at which time experiments proposed by numerous contractors (SNL was only one of many) and the armed services would be competitively reviewed for the limited space on the UGT. Design of accepted experiments continued up until D-1 year: according to Fritz Roessler (DTRA) both experiment designs and the test bed were “tweaked” during this period. These interactions with DNA were apparently frequent, intense, and held at distant sites such as Seattle, Palo Alto and NTS (Frank Dean, SNL Dept. 2132 [ret.]; personal communication), but we have included no costs for this aspect of the pretest buildup. We have assumed that our representative experiments would be executed as planned. At D-1 year all experiments were reviewed and approved again, and experiment configurations were nominally "frozen."

Fabrication of experiments began at this time. Despite that fact that testing was a year away, aboveground "pre-fits" began at a Lockheed facility in Seattle,[12] arranging experiment cassettes on mockups of the crowded partial bulkheads that would be installed in the LOS pipe (see for instance, the figure on p.37 of ref. [7]). Experiments were extremely closely spaced, and a great deal of effort went into maximizing usable square footage while ensuring that no experiment shadowed or shielded others from radiation exposure. We have not included any costs for SNL participation in these pre-fit exercises.

We have been told that the cassettes that housed the experiments were, themselves, pieces of careful engineering, often equipped with internal shock isolation to protect experimental specimens or assemblies that would be recovered, and using special breakaway bolts to speed recovery in the somewhat hazardous post-test environment. The cassettes also included filters to obtain the proper exposure at the experimental specimen or component, and shielding to protect the experiment from radiation scattered

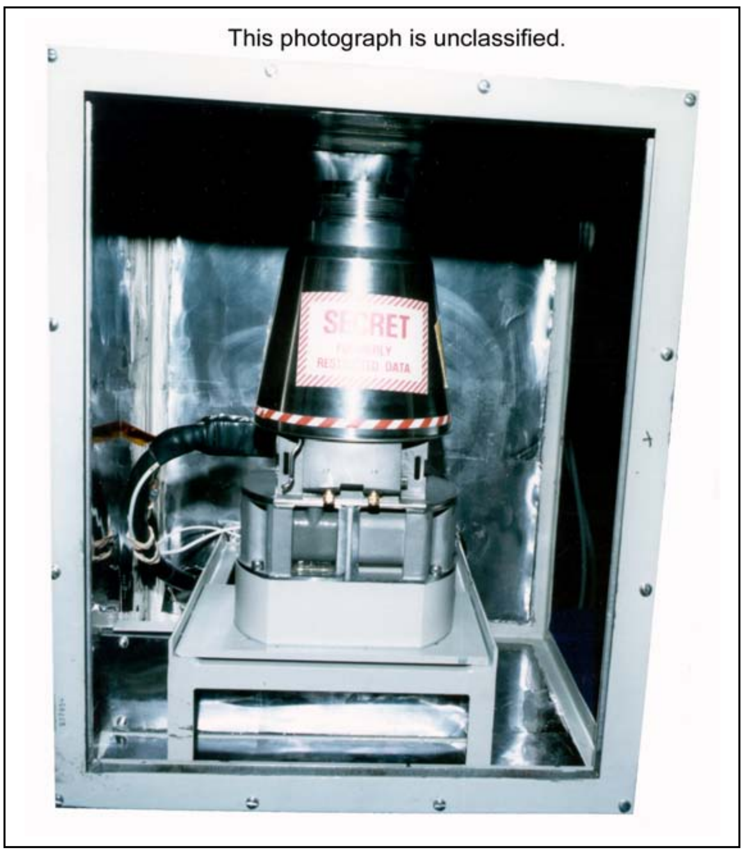


Figure 1: AF&F unit mounted in its cassette for active testing in the Middle Note event, 18 March 1987. The apparent left-to-right "key holing" of the cassette is an artifact of the photography. (Courtesy of Frank Dean.)

from adjacent experiments or other structures. Often, the cassettes included internal radiation diagnostics as well (calorimeters or total life dosimeters), to confirm the radiation environment at the experimental specimen. Explosive components had to be contained in special, six-sided cassettes for safety reasons, and also to protect adjacent experiments from destruction during operation of the components in "active" experiments. The number of explosive components per cassette had to be limited for the same reasons. Cassettes for explosive components also required testing to ensure that the explosions would be adequately contained. We have included costs for design, fabrication and testing of cassettes in our estimates. Interestingly, however, despite the fact that several of our experiment panelists emphasized the importance of cassette design and manufacture, we saw only a few sketches in the archived documents that we examined (see below). In Figure 1, we show an AF&F unit mounted in its cassette, being prepared for testing in the Middle Note effects test, executed in 1987.

From interviews with those who served on our six panels, as well as DTRA personnel with experience in underground testing, we learned that the final six months prior to a UG/NWET were extremely intense. This was the period of experiment and recording equipment installation, cabling between the two, numerous data recording checks using simulated test signals, and many dry runs. Underground signal conditioning and recording equipment was shock-mounted, in the hope (typically justified) that it could be protected and reused in later tests. Frequent travel between SNL Albuquerque or SNL Livermore, and NTS was required by project managers and experimenters, and we have included these costs in our estimates.

We will not further attempt to the describe the complexity of the experiment installation and testing phase, or the attention to detail required to successfully acquire data from hundreds of experiments that are over in a microsecond, and—worse yet—subsequently disturbed by the ground shock of a nuclear detonation. This is because despite the approximately one year that we have invested in this study, we are still far from knowledgeable about the complexity and intricacy of the task ourselves. The documentation that we were able to uncover in the course of this study does not preserve this complexity and intricacy, so most of what we have learned has been the result of interviews and discussions with our panel members. It is a source of concern to us that so little about the fine details of underground testing was written down for archival. With each passing year, this absence of documentation will make resumption of testing all the more difficult.

It is our observation that underground nuclear weapons effects testing was as much art as science, and that both were learned over a period of thirty years. (The first HLOS test was conducted in 1962, and the last in 1992.[11]) In order to try to understand how NWETs were conducted, we spent a substantial amount of time in both the classified Sandia library and archives at the Defense Threat Reduction Information Analysis Center (DTRAIAC) located on Kirtland Air Force Base in Albuquerque, NM. In particular, DTRAIAC is an outstanding repository of information about underground testing, and will be an invaluable resource in the event that testing is ever resumed.

Between the two document centers, we were able to retrieve the three overview "Program Officers Reports" (PORs) for a few of the more recent events, including Hunters Trophy, one of the two tests that we examined in some detail for the briefing (see Sections 2 and 4). These are the event Program Documents (PDs), Test Execution Reports (TERs) and Preliminary Results Reports (PRRs) which were written by the DNA Technical Director for the test.[11] These reports respectively summarized (1) the planned test program prior to experiment installation and testing, (2) test bed preparation and test execution and (3) preliminary assessment of the test environment and experimental results.[11] These three main reports were supported by any number of other "agency PORs" prepared by the experimenters themselves, which discussed experimental results in detail. Because we were interested principally in obtaining an understanding of how tests were conducted rather than experimental results, we examined only the "agency POR" for SNLs' experimental results for Hunters Trophy. We also examined archived SNL experiment planning documents for five events: Hunters Trophy, Middle Note, Mighty Oak, Misty Rain and Midas Myth.

Although our sampling of the UGT literature is admittedly limited, we nevertheless believe that it is accurate to state that the documentation is rich in technical detail regarding experiments and test bed, but seriously limited in other ways. Experiments were always clearly described with respect to (1) objectives, (2) descriptions, (3) relationship to previous experimental results, (4) supporting calculational and/or above-ground test results and (5) predicted results. A great deal of information is also available on the test facilities, *i.e.,* tunnel layout, line-of-site pipe and subcomponents (closures, seals, diagnostic stubs, *etc.*), and experiment layout on the LOS pipe bulkheads and elsewhere in the facility.

Interestingly, however, while discussion of specific experiments was often quite detailed, we found little mention of the data recording systems and the technology (*e.g.,* gas-blocking of cables) used to get the data first to the recording alcoves and then out of the tunnel altogether. The archived documentation that we were able to obtain also had absolutely no information on budgets and manpower, and scant information on timelines. Moreover, discussions with personnel who had long experience in underground testing confirmed our observation that there was a great deal of art to the design, installation and pre-test evaluation of experiments done in weapons-effects tests that was acquired by experience, and which was not written down in the archived, high-level planning and results documents.

What we learned of the art, we learned from our interviews, and from unpublished, internal working documents provided by our interviewees and panelists. In addition to the unpublished, internal SNL Project Management Plans for such tests as Hunters Trophy and Mighty Uncle to which we have referred above[9,10] we have seen reference[12] to numerous other internal SNL working documents prepared for each test that *may* have recorded some of this art; but unfortunately, if these documents exist, they probably now reside only in the personal files of past underground test personnel as did the Project Management Plans, which were obtained from William Barrett (SNL Dept. 15344), and reference [12], which was obtained from Frank Dean.

Much of the art and experience apparently came into play in recognizing the effects of test bed changes on experiments, and the on-the-fly adaptations that were made to preserve or improve upon an experiment's usefulness.[12] Reference [12] indicates that the HLOS test bed was modified frequently during both design and construction, and that experiments had to be adapted in response to these changes. It was the responsibility of the SNL Technical Director to continuously monitor test bed development with an eye to protecting Sandia's experiments. Similarly, minor last-minute changes to one experiment on a bulkhead could adversely affect other experiments; hence, the iterative need for prefits, X-ray alignments under vacuum, and corrections. One longtime UG/NWET experimenter, Frank Dean, summarized the value of experience and vigilance:[12] "You are the only one looking out for your experiment. There will always be someone doing something to compromise the experiment."

A number of our interviewees also remarked upon the important role of experienced technicians who could correct experimenter or drafting errors during installation—without immediately consulting staff—thereby saving time and money. Similarly, we learned of *ad hoc* approaches to shielding that were used, based on experience, to improve the quality of experimental results. Such approaches, which included shaping of lead bricks used for radiation shielding with a radial-arm saw, would not (and should not) pass muster in today's environmental health and safety-conscious workplace. (The bricks were sawn to square up edges and corners. As-received bricks had rounded edges and corners; when stacked, these resulted in radiation leaks.) But the key point here is that only long experience in underground testing could steadily increase the amount and quality of data that was successfully retrieved from these violent experiments.

Similarly, we learned from another of our interviewees, Dave Beutler (Dept. 15341) that every underground recorder was equipped with its own special, read-only memory chip, burned so that the recorder would return to its original configuration in the event that a power "glitch" occurred just prior to the event. Without such a chip, every recorder would have to be reset manually. According to Beutler, "there were hundreds of little techniques that were used to ensure that data were recorded accurately. Which ones have been forgotten?"

As noted in our briefing, that experience base is rapidly vanishing. And, as discussed in this section, very little of the art was written down for archival. Some documents may reside in the personal files of the dwindling number of experienced Sandia UG/NWET hands who remain. Access to any of this information is vanishing rapidly. For our briefing, we analyzed the status of SNL personnel who served on Hunters Trophy in 1992—the last effects test ever done—and Mighty Uncle, which was being planned in 1992, but was later canceled. We showed that fully half of the personnel who served on those tests have left Sandia, and that half of the remainder will be eligible to retire within 5 years (Ch. 4, Slide 32). Those who remain are doing work far removed from underground testing, and it is unknown how many of those would care to return to that type of work if the opportunity presents itself. Comments from our interviewees were highly disparate: some felt that given the opportunity, there would be a rush of personnel to return to underground testing, while others expressed concern that it would be extremely difficult to find such people. It is impossible to determine where the truth lies between those two extremes. As remarked by Paul Raglin, much may depend upon whether the return to testing is a "one-shot deal" or offers something resembling a career path.

Using the May, 1992 SNL telephone book and 2001 on-roll data, we also looked at the slightly larger population of what appeared to be Center 9300's (Radiation Test Center) seven core field test departments: 9311, Ground Motion and Seismic Department; 9312, Test Planning and Diagnostics; 9321, Instrumentation Development Department; 9322, Special Project Development and WIPP Instrumentation Department (excluding the WIPP instrumentation team in Carlsbad, NM); 9323, Test Planning and Fielding Department; 9324, NTS Field Operations Department; 9331, NTS Staff Department. The data are presented in Figure 2, and are entirely consistent with our observations for the personnel serving on specific tests: fully 50% of the population is gone.

We estimate that with experienced personnel mentoring new people, it should be possible to field an UG/NWET within the next five years. However, beyond that time, we believe that we will be virtually starting over.

As noted at the beginning of this report (Ch.1) and in the briefing (Ch.4), NNSA maintains a Test Readiness Program at NTS that is intended to preserve the capability to conduct underground performance/development tests. As part of that program, LLNL

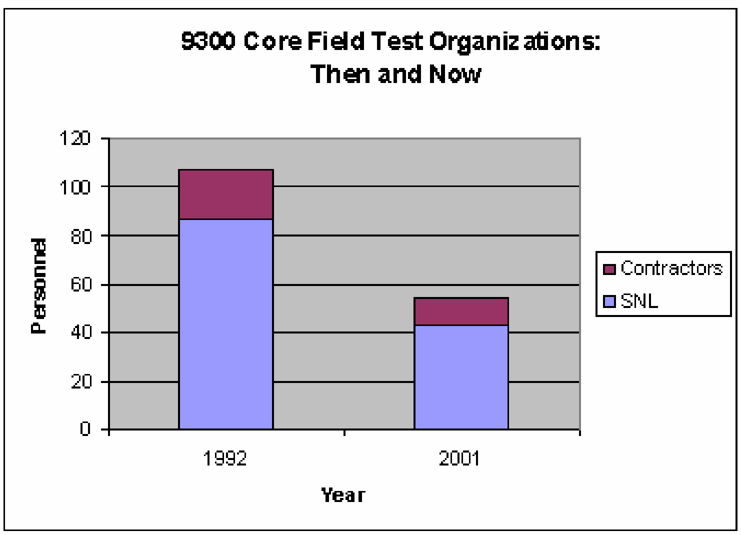


Figure 2: Number of 9300 core field test organization personnel still on roll (in any capacity) in 2001, as compared with the population in 1992, the year of the last HLOS test.

and LANL conduct underground, subcritical experiments on plutonium and plutonium alloys.[13] These are dynamic experiments on weapons-grade plutonium that are used to investigate the effects of aging weapon performance. The tests are conducted underground because the plutonium specimens are explosively destroyed in the experiment; the radioactive waste is simply entombed underground "minimiz[ing] the tests' environmental impacts." However, by conducting the experiments underground, eleven of fourteen "functional areas" associated with underground nuclear testing are also exercised.[14] It was by observing preparation for a subcritical experiment during a visit to NTS's U1a facility, and talking with William Kluesner (SNL) that we learned that we should assume for the purposes of this study that most data would be transmitted *via* fiber optics and recorded on the surface, a distinct change from the past.

During the course of this investigation we discussed with several of our subject matter experts the possibility of creating an "underground nuclear weapons effects test readiness" adjunct to the existing subcritical experiment program. In each discussion, we concluded that the existing program probably replicates as much of UG/NWET as possible simply by being carried out underground, and rapidly collecting and transmitting data to the surface in an environment that is as violent as possible without adding radiation. Nevertheless, the added expense of doing the subcritical experiments underground still requires some justification because the experiments could, in principle, be done aboveground. Ironically, the necessity for conducting the "subcrits" underground is waste management: the plutonium fragmented by explosives is contained in a steel tank which eventually will be permanently cemented-in underground. The fact that this necessity exercises UGT functional areas is a fortuitous coincidence.

Effects-type testing at the U1a facility would simply be doing an aboveground radiation effects experiment underground for the sake of doing so, and at the added expense of putting a very large piece of test equipment underground. Aboveground radiation effects testing does not result in any permanent contamination that needs to be isolated, providing a reason to be underground.

In summary, Sandia's capacity to field nuclear weapons effects tests will be steadily eroded over the next five years owing to (1) steady depletion of experienced personnel, (2) an inadequate base of archived material from which to reconstruct the "art" of effects testing, and (3) the intrinsic inability to fully preserve a complex capability without periodically exercising all of its facets.

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APPENDIX A

RESOURCES REQUIRED FOR ARMING, FUZING AND FIRING EXPERIMENT

Definition of AF&F Experiments
30 April 2002

A. Critical Review of the Experiment Definition

In this experiment, we would simultaneously expose and operate a WR-like AF&F. The objective of such a test might be to obtain data to support the certification process or to test an existing system to get insights into the effects of aging at the system level. This experiment would also stress the computational resources by requiring the definition and design of the appropriate exposure orientation, filtering and shielding. The most complex test would be the test of the AF&F in the radar fuzing mode.

We would not use a WR AF&F, because they are one-shot devices that can't be operated during the pretest dry runs. We would use specially modified AF&Fs that could be operated repeatedly prior to actual exposure in the UGT. We would want to have the system operating during exposure, so simulators would be used to mimic the operating environment of the AF&F. A minimum of four sets of AF&Fs and simulators would be required to provide redundancy in case the UGT device produces a high or low radiation environment. The plan would be to have two AF&Fs set for level X and two set for level Y and two different orientations at each expected fluence level.

B. Definition of Resources

Estimate of experimental detail

- **Assumptions** : No explosive components used**.** Test done in an air scatter station, with additional shielding to bring levels down to required.
- **Number of items/samples:** 4 AF&Fs and 4 testers capable of driving the specimens from up to 300 ft.
- **Cost per item:** Based on the W76 the AF&F cost would range from $400K for unit during development (uninstrumented) to $200K for units after production start. Adding instrumentation could run from $50K to $100K additional. The total cost would vary from $1M for instrumented production units to $1.8M for development units
- **Timeline to acquire:** These are not flight quality units; they are special builds that bypass environmental sensors. Some units actually operated off of the batteries, and from external power. Resettable strong links also are needed. Need to be requested at least two years in advance.

Estimate to design and build filters, gauges, experimental holder etc.,

- **Timeline:** Materials and shields built by Field Test. 1 month to design & fabricate filters located at each experimental box. 18 months to design & obtain diagnostics (Au calorimeters for X-rays, 1-2 per box).
- **FTEs:** 1 FTE

- **ODCs :** $0.7M

Estimate of pre-test modeling and simulation work required

- **Assumptions (models, runs, objectives etc.,):** Probably no pre-test modeling or simulation: this is a functionality test. *If there were, it would be to predict the radiation environment, which should be included in the estimate in the section above.*
- **Timeline:** N/A
- **FTEs:** N/A
- **ODCs:** N/A

Estimates of AGT pre test requirements

- **Assumptions (simulators, runs, objectives etc):** We would do a comprehensive AGT series to evaluate & eliminate undesirable secondary effects on the experiment set-up. These would test the entire set-up in the UGT configuration for undesirable effects. Post-test data could be evaluated in a period of 1 hour, two-three shots per day.
- We would also do direct injection experiments on the shielding system to evaluate upset. Kilovolt pulsers are available here at SNL to do these tests.
- **Timeline:** 3-6 months doing pre-test checkout. Hermes (perhaps 1-2 weeks testing), Saturn (1-2 weeks @ $125K/week). ACRR (1 destructive test on functioning AF&F).
- **FTEs:** 1 FTE
- **ODCs:** Will need 2 additional AF&F for the AGTs, as they probably cannot be used again underground. That would be $900K to $500K instrumented (development builds or production builds respectively). The Hermes and Saturn costs would be $70K per week for a total of $140K to $280K.

Estimates of down hole experimental "simulators/testers"

- **Assumptions (objectives, etc.):** MUX simulator is not required as AF&F can be used for dry runs. End-event signals were simulated with a separate box. Testers are needed.
- **Timeline:** At least two years to design and build, with testers available for checkout in the AGT series.
- **FTEs:** 4 FTEs.
- **ODCs:** **$**250K each for 5 testers that include radar simulation, for a total of $1.25M (current dollars).

Estimates of Data Acquisition requirements:

- **Number of signals to be recorded:** Three hi-voltage detonator signals, three hi-frequency current monitors (CVTs), 1 data MUX with 24 analog channels ; 2 additional back-up channels for the CVTs. The backup channels only indicate occurrence, not how much current.
- **Signal bandwidth;** CVTs: 100 MHz; Hi-voltage: low-frequency; Diagnostics: 2 Au calorimeters at the experiment.
- **Recording time/length;** CVTs: 500 nanoseconds; others on the order of minutes.

- **Required signal conditioning:** Data MUX require buffers/amplifiers and isolation. Radar channels are isolated w/ DC blocks and power supplies are floated.

Estimates of instrumentation installation fielding and checkout:

- **Assumptions (objectives, etc.,)**
- **Timeline:** Hardware required at site 6 months ahead to be set up and ready for the dry runs. 2 weeks to set up instruments, another month to confirm signals.
- **FTEs:** For the first few weeks, up to five FTEs on site, 2-3 personnel for the full 6 month lead-in, for a total of approximately 1 FTE.
- **ODCs:** Moving van: $50/hr for van and driver total trip time 15 hours for a total cost of $750. . Round-trip weekly for 2-3 personnel for 6 months + lodging for a total of approximately $33K. (RT weekly, $120 per trip, lodging/meals/transportation $50/day).

Estimates of experiment recovery:

- **Assumptions (objectives, etc.,)** Everything will be pulled out. Down hole data on disks physically recovered, in addition to above-ground data collection. Instrumentation eventually shipped back following storage, swiping and packing.
- **Timeline:** 1 long week: removal, storage, swiping, packing and shipping.
- **FTEs**: Approximately 0.
- **ODCs:** Shipping cost: moving van $750. Travel for recovery personnel, for a total of $3K.

Estimate of post-test analysis:

- **Assumptions (objectives, etc.,):** Inspect AF&Fs and confirm functioning from the recorded data. If one fails to function, a postmortem is performed. There apparently was no routine disassembly & examination. Some post-test function testing was done.
- **Timeline:** 2 months analysis and report writing.
- **FTEs:** 3 personnel; engineer, tech & x-ray environment analyst, for a total of 0.5 FTE.
- **ODCs:** If post-mortems done, KC would probably do the work.

APPENDIX B

RESOURCES REQUIRED FOR CABLE AND CAVITY SYSTEM-GENERATED ELECTROMAGNETIC PULSE (SGEMP) EXPERIMENTS

Definition of Cable and Cavity SGEMP Experiments
7 March 2002

I. Cable SGEMP Experiments

A. Critical Review of the Experiment Definition

As described in the original test matrix document, this is a reasonably well-defined experiment. The principal requirement for this meeting is to bring the details into focus. This includes specifying type and number of cables, in particular.

B. Definition of Resources

Estimate of experimental detail

- **Assumptions:** The principal assumption is that WR-like cables will be available. It may be difficult to obtain actual WR cables. Cable nominal length would be 3 feet. The test surface area would be approximately three feet by 10 inches. There would be two such areas for the cables, one at each fluence.
- **Number of items/samples:** We would want to test three types of cables: neutron generator, pre-set (these are specific AF&F Cables) and "generic" cables. We would test two of each type of cable at two different fluences and background, for a total of eighteen cables. We would also do two measurements per cable for redundancy. This yields 2 X 18 or 36 signals for the cables. Would also do 3 each gold and copper calorimeter measurements and 1 temporal measurement of fluence.
- **Cost per item:** $20K per cable type for a total of $60K.
- **Timeline to acquire:** 6 months.

Estimate to design and build sieves, filters, gauges, experimental holder etc.,

- **Timeline:** 9 months.
- **FTEs:** At least one FTE.
- **ODCs:** Would have to buy new filter materials & build boxes. Would also have to acquire connectors, shielding and interface circuitry. Estimate $150K-$200K total.

Estimate of pre-test modeling and simulation work required

- **Assumptions (models, runs, objectives etc.):** We are assuming that the Cable SGEMP codes are ready. They should be ready by FY03 under the current ASCI program.
- **Timeline:** 6 months pre-test simulation.
- **FTEs:** 0.5 to 1.0 staff FTE to do the pre-test simulations.
- **ODCs:** $10K.

Estimates of AGT pre-test requirements

- **Assumptions:** This would not add to cost. AGTs would already have been done on any cables of interest. The assumption here is if we took cable underground to test we would not do any new AGTs simply for the UGT. We are already planning AGT for V&V of cable models.
- **Timeline:** N/A
- **FTEs:** N/A
- **ODCs:** N/A

Estimates of down-hole experimental "testers"

- **Assumptions (objectives, etc.):** We are assuming that the "testers" will be needed and that they don't exist
- **Timeline:** Three months to design and build "testers" which would simulate the expected cable response signals to test the data acquisition system.
- **FTEs:** 0.2 FTE.
- **ODCs:** $50K.

Estimates of Data Acquisition requirements

- **Number of signals to be recorded:** 50 signals: 36 (plus optical fiber drivers) for cables, 12 for calorimeters and 2 for temporal fluence measurements.
- **Signal bandwidth:** 500 MHz digitizers for cables and temporal fluence sensors. Calorimeters will be slower.
- **Recording time/length:** Approximately one microsecond
- **Required signal conditioning:** Some compensation will be required.

Estimates of experiment fielding, installation and check-out:

- **Assumptions:** What follows covers installation and checkout of experimental setup down-hole: connect cables, install shielding, haul lead and support the data acquisition dry runs.
- **Timeline:** Three months.
- **FTEs:** 1 staff and 1 tech, generally on-site for three months.
- **ODCs:** Travel and incidentals, $35K.

Estimates of experiment recovery:

- **ODCs:** Add $15K for recovery and shipping.

Estimates of post-test analysis:

- **Assumptions:** Boxes will be disassembled and cables will be examined, sectioned and studied microscopically. Model runs would also be done, for comparison with the post-test observations. Some of this post-test analysis might include model runs with the measured spectrum, which, cynics tell us, will inevitably be different from the one used for pre-test analysis.
- **Timeline:** Six months
- **FTEs:** 0.2 FTEs for examination, 0.3 to 1.0 FTEs for post-test modeling.
- **ODCs:** $20K for specimen examination, probably nothing for post-test modeling.

II. Cavity SGEMP Experiment.

A. Critical Review of the Experiment Definition

The initial consensus (Fred Hartman and Gary Scrivner) was that this would essentially be an "Admirals" test involving a full up RB. The rationale was that we can currently conduct the necessary cavity V&V tests on various cavity sizes, shapes, orientations, and pressures in AGT facilities and the only reason for a UGT would be to achieve threat level over a full-up system. This would provide a good test of the state of our knowledge on cavity SGEMP. Since each test item (i.e. an RB) would probably require 3 to 4 sq. ft., we would limit this experiment to testing of three identical RB cavities at each of three different pressures: ambient, an intermediate pressure (TBD) and in vacuum. Assuming this was one in a series of tests we could test other parameters (i.e. fluence, orientation, etc.,) on the preceding tests if necessary.

B. Definition of Resources

Estimate of experimental detail

- **Assumptions:** WR-like hardware could be made available. Must include NGs and gas bottle to be realistic.
- **Number of items/samples:** 3 identical RBs.
- **Cost per item:** According to Tom Hendrickson, each of the experimental RBs would cost $800K, for a total of $2.4M.
- **Timeline to acquire:** 6 months. Acquisition time line could run in parallel with experiment design to determine where to place measurement gauges.

Estimate to design and build sieves, filters, gauges, experimental holder etc.,

- **Timeline:** At least one year including the time to determine best orientation, gauge location, acquisition and installation of gauges on the test article.
- **FTEs:** One FTE.
- **ODCs:** Gauges estimated to cost $10K-20K per, with 12 gauges per RB; minimum of $240K total, maximum of $480K. (See "Number of Signals" below for number & type of gauges.) Will need E-field & B-field sensors and current measurements. J. Hohlfelder indicates that current probes didn't work on Mission Cyber, so some developmental work might be necessary. Hohlfelder also indicates that E- and B-field sensors are large and complex.

Estimate of pre-test modeling and simulation work required

- **Assumptions:** Assume cavity SGEMP model is ready. This is the activity to make runs for orientation selection, gauge placements. And etc.
- **Timeline:** 1 year to prepare (mesh up) model and make runs.
- **FTEs** .5 to 1.0 FTE
- **ODCs:** $10K.

Estimates of AGT pre-test requirements

- **Assumptions:** Assume instruments (sensors and probes) have already been pre-tested. RBs are simply too large to be tested in AGT facilities.
- **Timeline:** N/A.
- **FTEs:** N/A.
- **ODCs:** N/A.

Estimates of down-hole experimental "testers"

- **Assumptions:** We are assuming that the "testers" will be needed and that they don't exist.
- **Timeline:** Three months to design and build "testers" which would simulate the expected cable response signals to test the data acquisition system.
- **FTEs:** 0.2 FTE.
- **ODCs:** $50K

Estimates of Data Acquisition requirements

- **Number of signals to be recorded:** Current probes (3 per body) and one other type of current measurement. Four (4) measurements each of E-field and B-field for a total of 12 measurements per RB, or 36 signals total.
- **Signal bandwidth:** 1 GHz.
- **Recording time/length:** Approximately one microsecond
- **Required signal conditioning:** Some compensation required. J. Hohlfelder also says that E- and B-field sensors require matched transmission lines to balance.

Experiment Fielding

- **Assumptions:** What follows covers installation and checkout of experimental setup down-hole: connect cables, install shielding, haul lead and support the data acquisition dry runs.
- **Timeline:** Three months
- **FTEs:** 1 staff and 1 tech, generally on-site for three months.
- **ODCs:** Travel and incidentals, $35K.

Experiment recovery and post-test examination

ODCs: Add $75K for recovery and shipping

Post-test modeling:

- **Assumption:** Assumes the mesh already done,
- **Timeline:** 6 months and
- **FTEs:** 0.5 to 1.0 FTE to do post-experiment runs.

IIA. Cavity SGEMP Experiment: ADDENDUM.

For the purpose of this study the experiment as defined above will be used for the cavity SGEMP test. Some felt that a more detailed experiment might be required. A definition of such an experiment is included below for completeness, but was not used explicitly in this study.

A. Critical Review of the Experiment Definition

In reviewing the foregoing “Admiral’s Test” (Sec. II) Dave Beutler expressed several concerns. First, spectra and fluence attainable in AGTs are greatly different from UGTs. Second, the RB cavities are too complicated and uncontrolled to be useful for validation. This opinion was seconded by Bill Barrett, Frank Dean and Brett Bedeaux in a “vetting” presentation. Beutler would not change the Admiral’s Test above, but would add the following:

B. Definition of Resources

Estimate of experimental detail

- **Assumptions:** RB cavities may be unreliable for use in code validation. Results from simple cavity shapes (cylinders, cubes, etc.) might be useful or necessary to interpret UGT results from RBs.
- **Number of items/samples:** Three special cavity designs would be used, tested at two fluences and three pressures, totaling 18 test cavities.
- **Cost per item:** The cost for each instrumented chamber would be $120K.
- **Timeline to acquire:** 1 year to build and test, which would probably run concurrent with design and testing of the “Admiral’s Test.”

Estimate to design and build sieves, filters, gauges, experimental holder etc.,

- **Timeline:** 1 year to build and test.
- **FTEs:** 0.5 FTE
- **ODCs:** Gauges have been estimated to be $10K-20K each. Measurements will be E- and B-field and current probes. J. Hohlfelder indicates that current probes didn’t work on Mission Cyber, so some developmental work might be necessary. Hohlfelder also indicates that E- and B-field sensors are large and complex.

Estimate of pre-test modeling and simulation work required

- **Assumptions:** Assume cavity SGEMP model is ready. Will do some modeling to determine best placement of sensors, etc.
- **Timeline:** One year to mesh up and make runs
- **FTEs:** 1.5 FTE over one year.
- **ODCs:** $10K

Estimates of AGT pre-test requirements

Assumptions: AGT will be done to shake down the experimental setup for unexpected interactions, test equipment and estimate sensor outputs.

Timeline: 6 months.

FTEs: 1.0 FTE over 10 weeks.

ODCs: 10 weeks at Saturn at $70K per week, $700K total.

Estimates of down-hole experimental "testers"

- **Assumptions:** We are assuming that the "testers" will be needed and that they don't exist. They can’t be the same testers that would be used for the "Admiral's test", because they will be used in the dry runs at the same time.

- **Timeline:** Three months to design and build "testers" which would simulate the expected cable response signals to test the data acquisition system.
- **FTEs:** 0.4 FTE.
  ODCs: $100K

Estimates of Data Acquisition requirements

- **Number of signals to be recorded:** 180 measurements (signals) with double recording for 360 channels.
- **Bandwidth:** 1 GHz
- **Required Signal Conditioning:** Some compensation required. J. Hohlfelder also says that E- and B-field sensors require matched transmission lines to balance. Sampling rate has to be 10 giga-samples per second.

Experiment Fielding

- **Assumptions:** What follows covers installation and checkout of experimental setup down-hole: connect cables, install shielding, haul lead and support the data acquisition dry runs.
- **Timeline:** Three months
- **FTEs:** 1 staff and 1 tech, generally on-site for three months.
- **ODCs:** Travel and incidentals, $35K.

Experiment recovery and post-test examination

ODCs: Add $25K for recovery and shipping

Post-test modeling:

- **Assumption:** Assumes the meshes already done. However, would use the measured final spectrum for modeling.
- **Timeline:** 1 year
- **FTEs:** 0.5 to 1.0 FTE to do post-experiment runs.

III Remarks

Cable Experiments: The analysts who might do this work are on role and currently working on these issues in the ASCI program. Fred H. has one staff member who has relevant experience on this type of UGT experiment. He is currently doing work on AGTs. Overall perception is that this experiment remains "do-able" within the next 5-10 yrs., beyond that we may lose key experienced capability.

Cavity: There are experienced personnel around, but not specifically with cavity tests. The experiments for AGT are being designed which should provide relevant experience to support a UGT as discussed above.

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APPENDIX C

RESOURCES REQUIRED FOR SHIELDING MATERIALS EXPERIMENT

Definition of Shielding Materials Experiments
12 April 2002

I. Shielding Materials Experiments

A. Critical Review of the Experiment Definition

Answer questions about the experimental definition: The materials to be tested will be materials proposed for use in shielding of AF&F in the RBs/RVs. Experiment types include coupons, rings and frusta. Small disc coupons used to measure TMS effects, with "stress" gauge mounted to coupon. Additional small coupons would be free standing to examine spall strength, damage, etc. Rings of material would be used to measure TSR effects and an actual size AF&F shield material frustum for combined effects

B. Definition of Resources

Estimate of experimental detail:

- **Assumptions:** Diagnostics 6 Au calorimeters, 2 per level. Also it is assumed that there will be an adequate suite of radiation diagnostics in the LOS pipe.
- **Number of items/samples:**
  1. TMS coupons: 10 materials at 3 levels, 3 specimens per materials, for a total of 90 specimens. One stress gauge per specimen, two scopes per channel.
  2. Passive spall/damage coupons: 10 materials at 3 levels and 3 specimens per materials for total of 90 specimens. No instrumentation.
  3. TSR rings: 5 materials at 2 levels, 3 rings per materials for a total of 30 rings. 5 strain gauges and one impulse gauge per ring.
  4. Frusta: 3 materials at two levels for a total of 6 specimens. 12 strain gauges, and two displacement gauges per frustum. Two scopes per channel.
- **Cost per item:** TMS gauges: $1500@, Passive: $500@, Rings: $10K@ and Frusta $50K@
- **Timeline to acquire:** 2 years to design materials; 1 year AGT to evaluate, 2 years downselect and UGT buildup.
- **FTEs:** 2-3 FTEs over 5 years.
- **ODCs:** The total cost for all experimental test item is $780K

Estimate to design and build filters, gauges, experimental holders etc.,:

- **Timeline:** Two years, but in parallel with the last two years of timeline to acquire materials.
- **FTEs**: An average of 2 FTE spread over 2 years
- **ODCs:** $100K per year for total of $500K

Estimate of pre-test modeling and simulation work required:

- **Assumptions (models, runs, objectives etc.,):** Codes and material models are being worked on now for example TMS models, spall models, TSR model, esp. for porous materials. The assumption is these models will have been completed before UGT testing.
- **Timeline:** Four year running in parallel with the last four years of the test item acquisition.
- **FTEs:** 3
- **ODCs:** $50K/year for total of $200K

Estimates of AGT pre test requirements:

- **Assumptions (simulators, runs, objectives etc.,):** The assumption is that we will use Z facility, Saturn, e- Beam for tests in years in the first two years of test item acquisition.
- **Timeline:** Three years running in parallel with the last three year of the time to acquire test items.
- **FTEs:** 2 (separate from the materials designers; these are the test fielders.)
- **ODCs:** 4 weeks of Z per year (only last 2 years) and 6 weeks of Saturn per year for three years. The costs are year 1 at $750K, year 2 at $2.3M/yr, and year 3 at $2.1M/yr, and $300K/yr for materials and contractor support, for a total cost of $4.7M.

Estimates of down hole experimental "simulators/testers":

- **Assumptions (objectives, etc.,):** For this experiment we will only need Signal generators for DAS testing
- **Timeline**: 6 months to acquire
- **FTEs:** 0
- **ODCs:** 0

Estimates of Data Acquisition requirements:

Assumptions: All necessary timing, firing, monitoring and control signals will be provided as part of the overall UGT activity.

- **Number of signals to be recorded**: 708 (twice the 354 actual gauge signal). Duplication of recorded signal provides for output amplitude uncertainty. Plus six Gold calorimeters, which adds 6 signals.
- **Signal bandwidth:** Strain and displacement, 528 channels at 150 KHz; 180 at 500 MHz; and 6 at 1 KHz
- **Recording time/length;** Stress is 3 microseconds data signal, and strain and displacement data signals at 100 milliseconds.
- **Required signal conditioning:** 222 strain gauge signal conditioner units. 12 Displacement gauges require special signal conditioning. No conditioning required for stress and impulse gauges.

Estimate of instrumentation installation fielding and checkout:

- **Assumptions (objectives, etc.,)**
- **Timeline;** 6 months
- **FTEs:** 1.5
- **ODCs:** Travel and shipping: $50K

Estimates of experiment recovery:

- **Assumptions (objectives, etc.,):** This activity covers removal of all experiments and samples**.**
- **Timeline:** 2 weeks
- **FTEs:** 0.1
- **ODCs:** $10K

Estimates of post-test analysis:

- **Assumptions (objectives, etc.,):** Post-test computation and sectioning and examination of specimens
- **Timeline:** 1-2 years
- **FTEs:** 3 FTEs per year (includes both simulation analysis & metallography / examination).
- **ODCs:** $100K per year

APPENDIX D

RESOURCES REQUIRED FOR NEUTRON GENERATOR EXPERIMENT

Definition of NG Experiments
11 April 2002

I. NG Experiments

A. Critical Review of the Experiment Definition

Neutron Tubes (NT) and Generators (NG): This experiment would involve the exposure of a series of NTs and NGs to 3 x-ray dose levels in different materials. The objective is to assess the impact on the NT/NG by conducting both passive and active experiments. The active experiments involve firing the NG in the tunnel just after exposure and just before the ground shock (50 to 60 milliseconds). Need true six-sided explosive containment. There will be 2 NGs per explosive container. Need 3 orientations: one side and two ends. Generators need to be stagger-fired, to accommodate neutron detectors. For the passive experiments, the NGAs are only exposed and recovered. They are fired and outputs measured aboveground.

B. Definition of Resources

Estimate of experimental detail:

- **Assumptions:** Active experiments: 3 levels of exposure, 3 orientations each (2 ends, 1 side), 27 NGAs total. Passive experiments: 3 levels of exposure, 3 orientations each (2 ends, 1 side), 27 NGAs total
- Number of items/samples: Total of 54 NGAs
- Cost per item: Could be as low as the transfer cost ($4K) or the actual ($50-60K) production cost
- Timeline to acquire: 1.5 year to acquire. Completion 6 months before test.

Estimate to design and build filters, gauges, experimental holder etc.:

- **Timeline:** (All completions 6 months before test)
  1. 1 yr to design & fabricate and test explosive containers (30+ test boxes) assuming 2 NGAs per box.
  2. 2 months to design & fabricate filters located at each experimental box.
  3. 2 yrs to design & fabricate triggers (2 Compton diodes for redundancy) used to initiate the fire signal to the fireset that fires the generators. The diodes are located somewhere in the tunnel.
  4. 24 months to design & obtain diagnostics (Au calorimeters for X-rays, 1-2 per box) and neutron detectors (1 per box, located in vacuum but well shielded and stubbed out to the side).
- **FTEs:** 5.5
- **ODCs:** $4M

Estimate of pre-test modeling and simulation work required at Sandia:

- **Assumptions (models, runs, objectives etc.,):** This would represent a significant validation effort. Pre-test runs used to predict sure-fail and sure-safe levels. Pre-test runs used to predict device levels, followed by runs to examine NGA response.
- Timeline: 1-2 years
- **FTEs:** 1
- **ODCs:** $10K

Estimates of AGT pre test requirements:

- **Assumptions (simulators, runs, objectives etc.,):** This would not involve the use of nuclear AGT facilities.
- **Timeline:** NA
- **FTEs:** NA
- **ODCs:** NA

Estimates of down hole experimental "testers":

- **Assumptions:** Firesets are required for the active NGA test articles. Number of Fire-sets required (worst case: 1 fireset per four NGAs) seven total, special-built. Depending on the timeframe of the test there may be some firesets in the inventory. New firesets will cost about $100K each. Cost used here assumes no firesets on the inventory. Passive experiments require only a tester to verify the signal of an Au calorimeter, the cost for which would be negligible.
- **Timeline:** 4 months
- **FTEs:** 1
- **ODCs:** $1M

Estimates of Data Acquisition requirements:

- **Number of signals to be recorded**: Active experiments: 4 signals per generator: High voltage, power supply current, regulator current, and trigger signal; and 3 per box: Neutron detector [one per box], 2 Au calorimeters per box.). This is a total of 3×27 plus 3×15, or 126 signals. The passive experiments only require signals from two Au calorimeters per cassette, or 3×15=45 signals. Thus, the total number of signals will be 171. However, number of recorders required could outnumber generator signals for redundancy and uncertainty in output level.

Signal bandwidth: NGA is a few microseconds; rise time is a few hundred ns.

- **Recording time/length:** less than 0.5 second
- **Required signal conditioning:** depends upon test bed configuration (FO vs. wire)

Estimate of instrumentation installation fielding and checkout:

- **Assumptions (objectives, etc.,):** Pre-test dry runs, installation of neutron detectors and mountains of shielding (combination of lead, sand and paraffin; paraffin on outside for neutrons; borated polyethylene inside paraffin). Includes the time for preparation and attendance at mandatory UGT planning meetings for experimenters.
- Timeline: 6 months, with completion 1 month prior to test**.**
- **FTEs:** 2

- **ODCs:** $100K (largely travel and shipping)

Estimates of experiment recovery:

- **Assumptions (objectives, etc.):** Photograph in situ, Pull out & open boxes, remove generators & fragments, inspect, photograph,
- **Timeline:** 2 months
- **FTEs:** 5 (all experimenters will want to go to observe disassembly)
- **ODCs:** $200K (largely travel and shipping)

Estimates of post-test analysis:

- **Assumptions (objectives, etc.):** Unfired active test generators disassembled & examined, electrical diagnostics; if OK, fire; if not, disassemble. Materials investigations, post-exposure. Passive generators fired and outputs measured aboveground on the test site.
- **Timeline**: 2 years, post-test
- **FTEs:** 2-3 FTEs
- **ODCs**: $200K

APPENDIX E

RESOURCES REQUIRED FOR EXPLOSIVE COMPONENTS EXPERIMENT

Definition of Explosive Devices Experiment
11Jun 02

I. Explosive Devices

A. Critical Review of the Experiment Definition (All)

Explosive Devices: This experiment would involve the test of several explosive actuators, detonators, and isolators. The purpose of these experiments is to measure the damage to explosive material from the interaction of the radiation and the explosive containment materials, and to determine the deflagration level in the various explosive materials. In addition we would include active experiments to address the effects of fratricide. These tests would be required if there are any changes to the explosive materials manufacturing process or if new containment or explosive material are introduced. This experiment is testing production-quality components. For statistical and radiation level uncertainties the experiment would require the use of 60 or 80 samples at each of two or three radiation levels, and at least two orientations per level. The number of samples for the active tests would be 30 or less. These experiments would be conducted in the HLOS pipe. Some of the test items would be used for passive testing and some would be tested actively. Because these are explosive components, special 6-sided containment cassettes are required.

B Definition of Resources

Estimate of experimental detail

- **Assumptions:** Active and passive testing would be done at two fluences and two orientations. This can be accomplished either by exposing a single cassette to one level of exposure with the cassette containing components in two orientations, or by exposing a single cassette to two levels of exposure (using a partial filter) with the cassette containing components in only a single orientation. We would design and build a special fireset to operate 4 detonators, or 4 actuators, or 2 timers, or 2 isolators at a time. The firesets would be installed outside the pipe and shielded. We are further assuming that (owing to the amounts of explosives contained therein), a single cassette can hold no more than: 5 detonators, or 5 actuators, or 2 timers or 3 isolators. However, detonators and actuators can be combined for active experiments (see attached matrix) in a single cassette, each cassette containing 4 detonators and 4 actuators for a total of eight components.
- **Number of items/samples:** For the passive experiments, a total of 30 detonators will be divided among two orientations and two fluences using the technique discussed above. A total of 20 actuators will be divided among and exposed to two fluences in two orientations, as will be 16 timers and 30 isolators (see attached matrix). For the active

tests, 16 actuators and 16 detonators will be tested, eight each at one orientation and fluence, and the other eight at the second fluence and orientation. 16 timers will be tested, 8 each at the first orientation/fluence combination, and 8 at the second orientation/fluence combination. 8 isolators will be tested, again evenly split between the first fluence/orientation and the second fluence/orientation combination. (See attached matrix for details.) That is a grand total of 46 detonators, 36 actuators, 32 timers and 38 isolators, with the cassette total being 16 for active experiments. In the active experiments, there will be 4 detonators and actuators per cassette, and 2 timers per cassette, and two isolators per cassette. The total number of firesets to support the active testing would be 16. In the passive experiments, there will be 5 detonators per cassette, and 5 actuators per cassette, 2 timers per cassette and no more than 3 isolators per cassette, for a total of 30 cassettes for the passive tests.

- **Cost per item:** For W76-like actuators the cost would be $200@; isolators would be $300-400@; special firesets would be $3K-4K@; detonators would cost $200@, and timers would cost $2000@. Total cost for test parts would be $140K-$160K.
- **Timeline to acquire:** Design, drafting, fabrication and testing of firesets would take 4 months. For the components, the timeline depends upon the production agency. Assuming emergency circumstances and a top priority, it would take12 months minimum to acquire.

Estimate to design and build sieves, filters, gauges, experimental holder etc.:

- **Assumptions:** We will need filters to get the two fluences we need. For passive cassette design, we can get a total of 5 detonators per single cassette and 5 actuators per single cassette. We can get only 2 timers per single cassette and no more than three isolators per cassette. For active experiments we can combine 4 actuators and 4 detonators in a single cassette. Limitations of only 2 timers or not more than three isolators per cassette remain. For active experiments, each component needs to be isolated itself in the containment cassette to prevent propagation of detonation. Au calorimeters will be used, 2 per cassette. TLDs (passive) will also be used for post-test reading. All active experiments would have a sensor to indicate operation.
- **Timeline:** 12 months to build filters, gauges and cassettes, including fielding
- **FTEs:** 2.7-3 FTEs
- **ODCs :** $5-6K per cassette times 46 cassettes, and an additional $10K for explosive testing of the four different types of cassettes, for a total of $240K to $286K.

Estimate of pre-test modeling and simulation work required

- **Assumptions (models, runs, objectives etc.):** These are already production-proven components, so there would be no need for modeling. We would do explosive simulation for the cassettes, but this is covered under containment testing.

- **Timeline:** N/A
- **FTEs**: N/A
- **ODCs:** N/A

Estimates of AGT pre test requirements

- **Assumptions (simulators, runs, objectives etc.):** No special AGTs would be done explicitly for the purpose of going underground.
- **Timeline:** N/A
- **FTEs:** N/A
- **ODCs:** N/A

Estimates of down hole experimental "testers"

- **Assumptions (objectives, etc.,):** Testers would be required. We would need something to generate the output of the isolator CVT, detonators, actuators and timers. The detonator, actuator and timer would require a resistive load with monitor points, and a pulse generator would be required. A special generator would be built for this purpose. A single box would work for multiple devices, maybe eight black boxes total.
- **Timeline:** Three months would be needed to design, build and test the "testers."
- **FTEs:** 0.1 FTE
- **ODCs:** $6K total would be needed for parts for black boxes.

Estimates of Data Acquisition requirements

- **Number of signals to be recorded:** For passive experiments, one calorimeter per cassette, for thirty signals. For active experiments, 16 detonator output cables, 16 actuator output cables, 16 timer output cables and 8 isolator output cables, and two Au calorimeters per cassette for a total of 88 signals from active experiments. This is a total of 118 signals. There would also be 24 input cables from the firing sets.
- **Signal bandwidth:** 200-300MHz
- **Recording time/length:** 2-3 milliseconds.
- **Required signal conditioning:** None

Estimates of instrumentation installation fielding and checkout

- **Assumptions (simulators, runs, objectives etc.):** We would ship explosive materials separately from the assembled cassettes, and final assembly would be done at NTS.
- **Timeline:** 2.5 weeks would be needed to do final assembly of the experiments and to prepare to go underground. Another two weeks would be required to get 46 cassettes underground. No other work can go on during explosive installation. The train carrying explosive cassettes can't carry anything else. 2.5-3.5 weeks would be needed for checkout, and 2 months would be needed for the mandatory dry runs, for a total of three and one-half months.
- **FTEs:** 2 FTEs for three and one-half months.

- **ODCs:** $2K for miscellaneous parts. Air: $200 per week per person for 14 weeks; plus rental car, $550 per week; plus per diem (meals and room--$30 per day per person in Mercury) for a total of $17.5K in travel. Shipping explosives to NTS: $3K, plus $2K for cassettes. This is a total of $24.5K.

Estimates of experiment recovery

- **Assumptions (simulators, runs, objectives etc**. All experiments will be recovered, and cassettes would be disassembled at NTS.
- **Timeline:** 5 days to retrieve, 5 weeks to disassemble, 6 weeks total. (Remember: we are retrieving explosive components!)
- **FTEs:** 2 people full-time.
- **ODCs:** Air: $200 per week per person for 6 weeks. Rental car: $550 per week for 6 weeks. Per Diem: $30 per day per person in Mercury for 6 weeks. This is a total of $7.5K in travel.

Estimates of post-test analysis

- **Assumptions**: If an active component does not fire, the component must be shipped backed to Albuquerque for analysis. There are no facilities at NTS to do this. Each passive component would then be tested at NTS aboveground, and each component would require a CVT, TOAD or pulse switch assembly, as well as firesets.
- **Timeline:** 2 months would be required to complete all testing. 2 months taken to analyze data and write and publish final report.
- **FTEs:** 2 people full time to complete testing. 3 people to complete data analysis and report.
- **ODCs:** CVTs (free), 16 TOADS (Time of Arrival Detectors) @ $35, 50 pulse switch assemblies @ $100, and two firesets. Parts total $11.6K-$13.6K. Air travel : $200 per week per person for 8 weeks. Rental car: $550 per week for 8 weeks. Per Diem: $30 per day per person in Mercury for 8 weeks. This is a total of $10K for travel, and a grand total of ODCs of $21.6K to $23.6K. Waste disposal would be done at NTS.

-

Passive Experiments						
	No. of Dets	No. of Actuators	No. of Timers	No. of Isolators	No. of Cassettes	Fluence/ Orien.
	10				2	1/1
	10				2	1/2
	10				2	2/2
		10			2	1/1
		10			2	2/2
			4		2	1/1
			4		2	2/1
			4		2	1/2
			4		2	2/2
				5	2	1/1
				5	2	2/1
				5	2	1/2
				5	2	2/2
				5	2	1/1
				5	2	2/1
Totals	**30**	**20**	**16**	**30**	**30**	

Total Passive Cassettes: 30
Total Passive Components: 96

Table 1: Passive Experiments

Active Experiments						
	No. of Dets	No. of Actuators	No. of Timers	No. of Isolators	No. of Cassettes	Fluence/ Orien.
	8	8			2	1/1
	8	8			2	2/2
			4		2	1/1
			4		2	1/1
			4		2	2/2
			4		2	2/2
				4	2	1/1
				4	2	2/2
Totals	16	16	16	8	16	

Total Active Cassettes: 16
Total Active Components: 56

Table 2: Active Experiments

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APPENDIX F

ON-SITE FIELD SUPPORT

Definition of On-Site Support at NTS
Aug 02

The estimates of resources were made for two phases of work. The first phase was the 2-year design phase and the second was the 8-month installation phase.

ASSUMPTIONS

1.) It was assumed that the resources for the individual cassette development and production were covered under the individual experiments.

2.) It was assumed that we would use fiber optic cable to bring the signals up from the tunnel and:

a) the recording would be done above ground in 12-909, and

b) primary signal conditioning would be done in the tunnel.

3.) LF was defined as DC to 3 Mhz, Mid Freq was defined as 3 MHz to100 MHz, and HF was defined as greater than 100 MHz.

4.) Three Recording Alcoves and one air scatter station.

5.) The installation duration will be 8 months.

6.) The majority of additional on-site support will come from BN.

7.) The Alcove Lead Engineers and Lead Techs are SNL personnel.

DESIGN PHASE

The first set of resources was the top-level test support.

Project Manager Group

Five personnel

- Half time for one year for a total of 2.5 FTE (MTS)
- Full time for one year for a total of 5.0 FTE (MTS)
- Full time for 8 months on site for a total of 3.3 FTE (MTS)
- Travel would be round trip air and car and per diem weekly for 8 months

General Support

Design Definition Team

- 8 techs working half time for one year for 4.0 FTE
- 15 techs working for one year full time for 15 FTE

Data systems

Project leader (1)

- Half time for one year for a total of 0.5 FTE
- Fulltime for one year for a total of 1.0 FTE
- Full time for 8 months for a total of 0.67 FTE

LF Design Team

Project leader (1)

- Half time for one year for a total of 0.5 FTE
- Full time for one year for a total of 1.0 FTE
- Full time for 8 months for a total of 0.67 FTE

Techs (2)

- Tech 1 is half time for one year and full time for one year for a total of 1.5 FTE over two years (recording and signal conditioning)
- Tech 2 is half time for two years for a total of 1.0 FTE (fiber optics)

Both techs full time for 8 months for a total of 1.33 FTE with travel.

HF Design Team

- Project leader (1)
  - Half time for one year for a total of 0.5 FTE
  - Fulltime for one year for a total of 1.0 FTE
  - Full time for 8 months for a total of 0.67 with travel
- Engineer (Kfactor/Equalization etc) (1)
  - Half time for one year for a total of .5 FTE
  - Full time for one year for a total of 1.0 FTE
  - 8 month on site with travel
- Techs (3)
  - Tech 1 is half time for two year for a total of 1.0FTE (Recording and signal conditioning)
  - Tech 2 is half time for two years for a total of 1 FTE (Fiber optics)
  - Tech 3 is half time for one year for a total of 0.5 FTE plus full time for one year for an additional total of 1.0 FTE (general support)
  - All three techs full time for 8 months plus travel

Software Design Team

- Project leader (1)
  - Half time for one year and full time for one year for 1.5 FTE
  - Full time for 8 month plus travel
- Engineer LF (1)
  - Half time for one year and full time for one year for 1.5 FTE
  - Full time for 8 month plus travel
- Engineer HF (2)
  - Half time for one year and full time for one year for 3.0 FTE
  - Full time for 8 month plus travel

Computer Hardware

- Project leader (1)
  - Quarter time for two years for a total of 0.5 FTE
  - Full time for 8 month plus travel
- One staff (1) (cryptology and computer security)
  - Full time for two years for 2.0 FTE
  - Full time for 8 month plus travel

Monitors and Commands

- Project leader (1)
  - Half time for one year and full time for one year for a total of 1.5 FTE
  - Full time for 8 month plus travel
- Tech (1)
  - Half time one year and full time one year for a total of 1.5 FTE
  - Full time for 8 months plus travel

Mechanical

Engineers (2) (Pre Fit board, Liasion for Experimeters)

Full time for 2 years for 4.0 FTE

Full time for 8 months plus travel

Capital Costs

Hardware Purchase

HF Hardware costs

HF Digitizer is $5K/Channel

Mid Freq Digitizer is $3K/Channel

Fiber optics Transmitter, Receiver, Calibrator/Conditioner $15K/Channel

Computer System and Data base $40K

LF Hardware

Total system (Digitizer,memory,rack,software,license,calibration) $300K/100 Channels

Fiber Optics Xmiter/Rcvr $5K/channel

Trigger and timing hardware $100K/100 Channels

Monitor and Command Hardware (could use LANL system)

Use Lab View

1 FTE total

Total cost of $10K/Channel

Facility Cost

Restore 12909

A/C Power, Plumbing, UPS, Pad Comm etc.

Assemble area For a total cost of $1M

Restore CP1 Rm 105

Comm, power A/C etc. for $250K

Scopes for CP 1

$5K/channel assuming 4 signals per scope using time delay

INSTALLATION PHASE

Assumptions: Three Recording Alcoves and one air scatter station

Duration will be 8 months

Majority of additional on site support will come from BN

Alcove Lead Engineers are SNL

Misc Material and Hardware

(connectors, nema box, jumper cables machine shop piece work, etc) $1 – 2M

UNDER GROUND

General Support

Alcove Engineers (3)

Alcove support techs (3)

Alcove HF fiber optic techs (6)

Alcove LF tech (3)

Cable Crew
Cable Techs (6)
Cable equalization Techs (3)
Fiber Optics Techs (5)
Engineering and construction Techs (2)
Computer Networking Crew
- Engineers (2)
- Techs (2)

Laser Alignment Crew
- Drawn from above personnel

ABOVE GROUND
Recording Crew
- LF channel techs (3)
- HF channel techs (1/every 30 channels)

Admin Crew
- Admin staff (3)

ES&H and Security
- Personnel (4)

QA
- 1 person

Data Base input Crew
- Data entry personnel (2)

Monitoring and Command
- 1 person

CP1 Rm 105
- Techs (2)

One point failure analysis team
- Drawn from above personnel

RECOVERY

Assume recovery could last for three months involving 5 to 6 personnel

Distribution:

1	MS-0121	Hart, C. M., 1200
1	MS-0130	Polito Jr., J., 2800
1	MS-0139	Vahle, M. O., 9900
1	MS-0143	Detry, R. J., 4000
1	MS-0151	Hunter, T. O., 9000
10	MS-0415	Almquist, K. A., 9741
5	MS-0415	Bomber, T. M., 9741
15	MS-0415	Zeuch, D. H., 9741
1	MS-0417	Ling, W.H., 9743
1	MS-0421	Wilson, R.K., 9730
1	MS-0421	Hines, W. C., 9740
1	MS-0423	Branstetter, L.J., 9747
1	MS-0423	Croessmann, C.D., 9732
1	MS-0427	Bedeaux, B. C., 2134
1	MS-0427	Paulsen Jr., R. A., 2134
1	MS-0429	Hartwig, R. C., 2100
1	MS-0429	Rottler, J. S., 2100
1	MS-0453	Abeyta, Henry J., 2130
1	MS-0453	Knapp, Corey L., 2120
1	MS-0457	Novotny Jr., G. C., 2001
1	MS-0457	Stichman, J. H., 2000
1	MS-0487	Sena, P. A., 2115
1	MS-0511	Fellerhoff, Rick, 1020
1	MS-0515	Barnhart, S. G., 2561
1	MS-0521	Damerow, R. A., 2561
1	MS-0527	Royer, E. P., 2565
1	MS-0736	Blejwas, T. E., 6400
1	MS-0824	Hermina, Wahid, 9110
1	MS-0865	Cook, D. L., 1900
1	MS-0868	McCaughey, K. G., 14400
1	MS-0874	Palmer, D. W., 1751
1	MS-0896	Partridge, M.E., 2665
1	MS-1106	Mikkelson, K. A., 15342
1	MS-1140	Reil, K. O., 6423
1	MS-1154	Keese, D.L., 15404
1	MS-1156	Tachau, R. D. M, 15322
1	MS-1159	Barrett, W. F., 15344
1	MS-1159	Dean, F. F., 15344
1	MS-1159	Hedemann, M. A., 15344
1	MS-1165	Guyton, W., 15300
1	MS-1166	Scrivner, G. J., 15345
1	MS-1167	Hartman, E. F., 15343
1	MS-1179	Lee, J. R., 15340
1	MS-1179	Lorence, L., 15341

1	MS-1190	Quintenz, J. P., 1600
1	MS-1217	Gronager, J. E., 5913
1	MS-1219	Craft, C. M., 5921
1	MS-1391	Thomson, D. D., 1614
1	MS-1453	Scharrer, G. L., 2553
1	MS-9007	Henson, D.R., 8200
1	MS 9018	Central Technical Files, 8945-1
2	MS 0899	Technical Library, 9616