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Forecast of Criticality Experiments and Experimental Programs Needed to Support Nuclear Operations in the United States of America:

1994–1999

Los Alamos
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Forecast of Criticality Experiments and Experimental Programs Needed to Support Nuclear Operations in the United States of America: 1994–1999

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Foreword

This report identifies critical experiments forecast for 1994-1999, which are based on the concensus of the Experiment Needs Identification Workgroup (ENIWG). Generated by the chair of the workgroup, this *Forecast* is considered a living document and will be updated periodically. It includes a listing of the ENIWG members and their addresses; an overview that has specific information pertaining to priority-1 critical expèriments, facilities, and programmatic resources; and physics criteria for benchmark experiments.

The *Forecast* has been divided into sections, each with a separate table of contents. Refer to the Table of Contents at the beginning of the document for information on the section you wish to access. Appendix A contains a glossary of nuclear criticality terms to help you with the nomenclature.

FORECAST OF CRITICALITY EXPERIMENTS AND EXPERIMENTAL PROGRAMS NEEDED TO SUPPORT NUCLEAR OPERATIONS IN THE UNITED STATES OF AMERICA: 1994-1999

by

Debra Rutherford

ABSTRACT

This *Forecast* is generated by the Chair of the Experiment Needs Identification Workgroup (ENIWG), with input from Department of Energy and the nuclear community. One of the current concerns addressed by ENIWG was the Defense Nuclear Facilities Safety Board's Recommendation 93-2. This Recommendation delineated the need for a critical experimental capability, which includes (1) a program of general-purpose experiments, (2) improving the information base, and (3) ongoing departmental programs. The nuclear community also recognizes the importance of criticality theory, which, as a stepping stone to computational analysis and safety code development, needs to be benchmarked against well-characterized critical experiments. A summary projection of the Department's needs with respect to criticality information includes (1) hands-on training, (2) criticality and nuclear data, (3) detector systems, (4) uranium- and plutonium-based reactors, and (5) accident analysis. The Workgroup has evaluated, prioritized, and categorized each proposed experiment and program. Transportation/Applications is a new category intended to cover the areas of storage, training, emergency response, and standards. This category has the highest number of priority-1 experiments (nine). Facilities capable of performing experiments include the Los Alamos Critical Experiment Facility (LACEF) along with Area V at Sandia National Laboratory. The LACEF continues to house the most significant collection of critical assemblies in the Western Hemisphere. The staff of this facility and Area V are trained and certified, and documentation is current. ENIWG will continue to work with the nuclear community to identify and prioritize experiments because there is an overwhelming need for critical experiments to be performed for basic research and code validation.

Executive Summary

This report identifies critical experiments forecast for 1994-1999, based on the consensus of the Experiment Needs Identification Workgroup, which is sponsored by the Department of Energy's (DOE) Nuclear Criticality Technology and Safety Project. This *Forecast* is generated by the Chair of the Workgroup, with input from DOE contractors, DOE program offices, special groups working in the area of criticality safety, DOE critical mass laboratories, and the Nuclear Regulatory Commission.

I. The Need for Critical Experiments and Experimental Programs

One of the current concerns addressed is the Defense Nuclear Facility Safety Board (DNFSB) Recommendation 93-2, which delineated the need for a critical experimental capability. Specifically, the Board recommends that:

1. The Department of Energy should retain its program of general-purpose critical experiments.
2. This program should normally be directed along lines that satisfy the objectives of improving the information base.
3. The results and resources of the criticality program should be used in ongoing departmental programs where nuclear criticality would be an important concern.

Criticality physics and calculational methods being used for criticality analysis are extremely important as the DOE complex changes its mission, as it faces numerous returns from the stockpile, and as regulatory compliance along with environmental restoration become driving forces. Criticality theory, which is a stepping stone to computational analysis and code development for criticality safety, therefore needs to be benchmarked against well-characterized critical experiments. Specific experimental and programmatic responses to the DNFSB Recommendation are listed in Table I.

Table I: Experiments and experimental programs identified by ENWIG that address specific DNFSB Recommendations.

DNFSB Recommendation	Experiments or Experimental Programs that Address the Recommendation
". . . maintain a good base of information for criticality control, covering the physical situations that will be encountered in handling and storing fissionable material . . ."	104, 106, 202, 203, 302, 303, 305, 306, 402, 502g, 502h, 504, 406, and 701
". . . theoretical understanding of neutron multiplication processes in critical and subcritical systems . . ."	103, 105, 204, 205, 207, 208, 301, 501, 502, 502a, 502d, 502e, 502f, 502i, 503, 505, 601, 605, 605a, 609, 702, 703, and 704
". . . to ensure retaining a community of individuals competent in practicing the [criticality] control."	All experiments and experimental programs, specifically 507 and 508 - training
". . . experiments targeted at the major sources of discrepancy between the theory and the experiments . . ."	101, 102, 304, 606, and 707

II. The Need for a Critical Facility

The DOE and DNFSB's requirements show the overwhelming need for a critical facility. A critical facility typically operates with core configurations at zero power, versatile fuel configurations, little or no heat removal, and minimal fission product controls. These systems lend themselves to the ease of physics data acquisition and system change. Only DOE's Defense Programs have this breadth of facility technology and criticality knowledge. The following list is a summary projection of the Department's needs with respect to nuclear data and criticality information:

II. The Need for a Critical Facility (continued)

1. Hands-on training;
2. Criticality and nuclear data on
   a. super prompt criticals and fast configurations,
   b. new fuels for space propulsion and wide temperature ranges,
   c. new fissile material configurations,
   d. storage arrays,
   e. transuranics and actinides (for spent-fuel processing), and
   f. auxiliary-power reactors;
3. Detector systems with neutron and gamma burst and steady state test systems;
4. Uranium- and plutonium-based reactors; and
5. Accident analysis.

III. Criticality Experiments and Experimental Programs

All proposed experiments and experimental programs needed to support our nuclear operations have been assigned to one of seven categories listed in the table below. Each of these categories has a separate section in this report (the parenthetical abbreviations in the table). Experimental programs delineate general representations of a broad experimental need (i.e., dosimetry). Experiments are more specific in nature. At the beginning of each experiment and experimental program listing, the following general information is given: (1) the contractor requiring the experimental data, (2) the experiment or experimental program category; and (3) the application of the experiment or experimental program.

Each experiment listed in this document has a *priority* listing that is one of the following: (1) Maximum practical attention; (2) Required for new or ongoing DOE operation; or (3) Less urgent than priority (2). The *status* ranking of each experiment is designated as one of the following: (1) Justification Completed, (2) Justification Being Prepared, (3) Experiment Identified, (4) Anticipated Need, (5) Experiment in Progress, or (6) Experiment Complete. Note that *status* and *priority* are different and can differ for any single experiment and experimental program. However, every effort should be made to bring them to an equivalent level so that, for instance, the highest priority experiments should also be the ones closest to completion. Table II lists the 59 experiments that have been identified and prioritized.

Table II: Identified and Prioritized Experiments.

		Number of Priority		
Categories		Priority 1	Priority 2	Priority 3
Highly Enriched Uranium	(HEU)	2	5	0
Low-Enriched Uranium	(LEU)	2	5	1
Plutonium	(P)	4	1	0
Plutonium/Uranium Fuel	(PUF)	0	1	2
Transportation/Applications	(T/A)	9	8	0
Baseline Theoretical	(BT)	6	2	4
Criticality Physics	(CP)	1	5	1
	Total (59)	24	27	8

III. Criticality Experiments and Experimental Programs (continued)

Transportation/Applications is a new subset of criticality experiments that is intended to cover the areas of storage, transportation, waste, dosimetry alarm systems, training, emergency response, processing, and regulations and standards. Training is included as part of continuing capability.

IV. Resources and Status of Facilities

Los Alamos Critical Experiment Facility (LACEF). Much of the original nuclear criticality research was performed at this site, and the facility continues to house the most significant collection of critical assemblies in the Western Hemisphere. The combination of the assemblies, a large inventory of fissile material, and structural materials makes the LACEF one of the most diversified facilities for the simulation of nuclear reactors, weapons, and process applications; it is also a resource for performing research for the nuclear community. The LACEF staff is trained and certified and documentation is current.

Area V, Sandia National Laboratories (SNL). Area V at Sandia National Laboratories (Albuquerque, New Mexico) comprises numerous research and test laboratories whose main activities center upon research work conducted at versatile reactors and gamma-ray source facilities. The SNL staff is trained and certified and documentation is current.

Other Facilities. Argonne National Laboratories (West), the location of the Zero Power Physics Reactor (ZPPR), Hanford Laboratories and the Hanford Critical Mass Laboratory, Oak Ridge National Laboratory (ORNL), and Rocky Flats are either on stand-by or have been shut down.

V. Conclusions

An evaluation of experimental status and priority indicates the following:

- The majority of Priority-1 experiments and experimental programs (9) are in the Transportation/Applications category, with the Baseline Theoretical and Plutonium categories having 6 and 4 Priority-1 experiments and experimental programs, respectively.
- Criticality safety training is recognized as one of the most important aspects of maintaining our technical capability.
- The new priorities for needed experiments reflect the change in the mission of the DOE and the current thinking in the nuclear community.

Future Directions. There is an overwhelming need for critical experiments to be performed for basic research and code validation. The Workgroup will continue to work with the changing direction of the DOE and the nuclear community to identify experiments and prioritize them.

The Experiment Needs Identification Workgroup and the Evaluation of Proposed Criticality Experiments

D. Rutherford, Los Alamos National Laboratory

I. Introduction

From July 27 through 28, 1993, the Experimental Needs Identification Workgroup (ENIWG) held a meeting to discuss the current and projected needs for criticality experiments and facilities. Sponsored by the Department of Energy's (DOE) Nuclear Criticality Technology and Safety Project (NCT&SP), the ENIWG comprises representatives from the following communities: DOE contractors, DOE program offices, special groups working in the area of criticality safety, DOE critical mass laboratories, and the Nuclear Regulatory Commission (the map on the following page shows the location of the DOE nuclear facilities involved in the Workgroup). At this meeting, the Workgroup identified those nuclear criticality experiments that are necessary to support the DOE's changing programs and diverse production operations. This *Forecast* is generated by the Chair of the Workgroup, with input from the aforementioned groups.

This document is considered a "living" document and will be updated periodically. A glossary of nuclear criticality terms and a list of symbols used in this report can be found in Appendix A. A list of criticality acronyms can be found at the end of this section, along with a list of ENIWG participants.

Current Concerns. The Defense Nuclear Facilities Safety Board unanimously approved Recommendation 93-2 (Appendix B) which deals with "the need for critical experiment capability." The Board delineated in its Recommendation that a continuing program of general-purpose critical experiments is necessary to insure safety in the handling and storing of fissionable material. Specifically, the Board recommends that:

1. The Department of Energy should retain its program of general-purpose critical experiments.
2. This program should normally be directed along lines that satisfy the objectives of improving the information base, which underlies the prediction of criticality and serves in the education of the criticality engineer community.
3. The results and resources of the criticality program should be used in ongoing departmental programs where nuclear criticality would be an important concern.

Specific experimental and programmatic responses to the DNFSB Recommendation are listed in Table I.

Also, based on the previous version of this forecast, several questions were raised concerning criticality physics and the calculational methods being used for criticality analysis. These evaluations and questions become extremely important as the DOE complex changes its mission, faces numerous weapons returns from the stockpile, and places an ever increasing importance on regulatory compliance. Because the experimental facility chosen must conduct their operations based on their financial and personnel resources, the ENIWG provides the guidance and information that are needed for the allocation of resources in the early planning of criticality experiments.

USA Department of Energy Nuclear Facilities

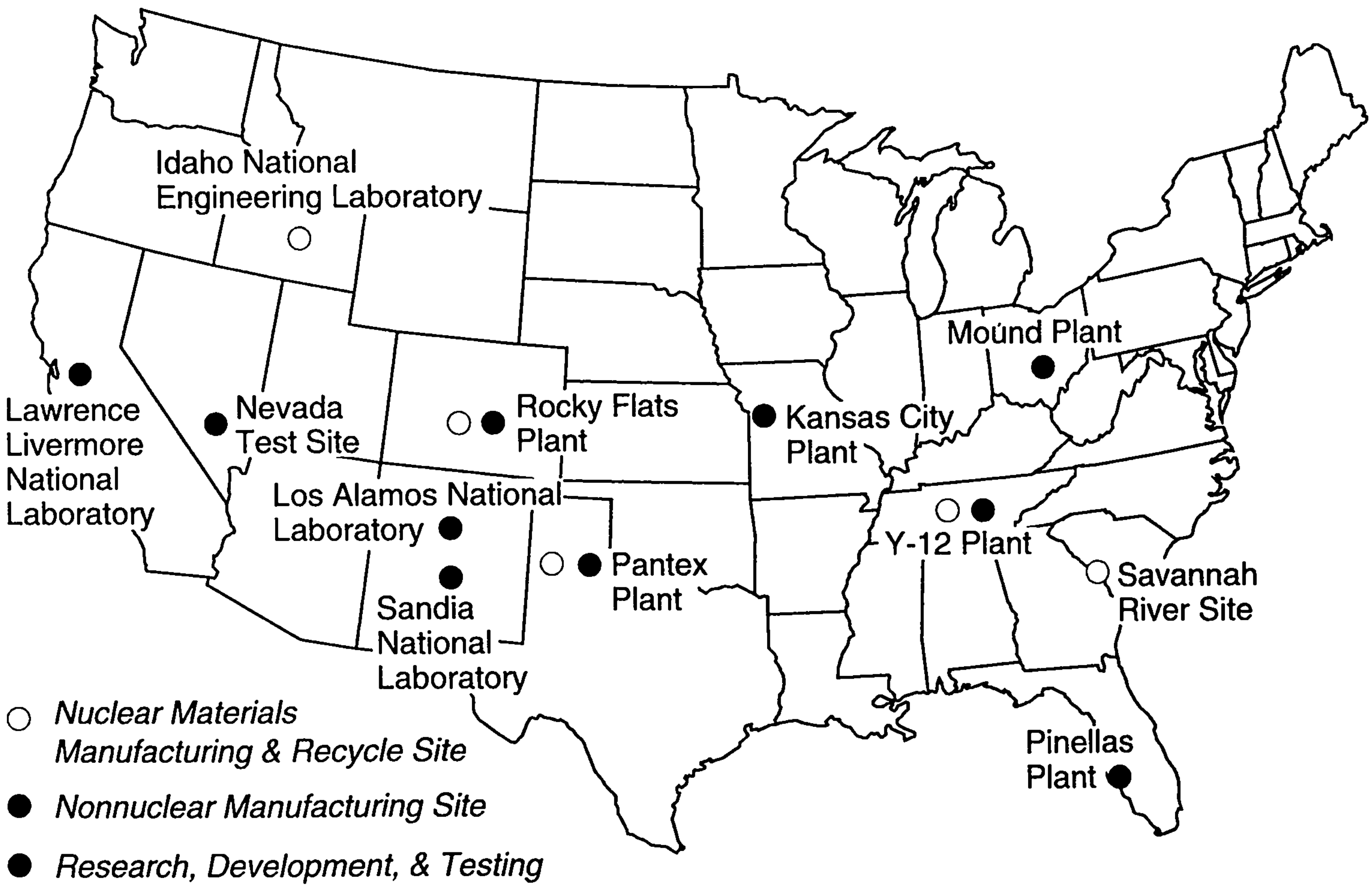

Table I: Experiments and experimental programs identified by ENWIG that address specific DNFSB Recommendations.

DNFSB Recommendation	Experiments or Experimental Programs that Address the Recommendation
". . . maintain a good base of information for criticality control, covering the physical situations that will be encountered in handling and storing fissionable material . . ."	104, 106, 202, 203, 302, 303, 305, 306, 402, 502g, 502h, 504, 406, and 701
". . . theoretical understanding of neutron multiplication processes in critical and subcritical systems . . ."	103, 105, 204, 205, 207, 208, 301, 501, 502, 502a, 502d, 502e, 502f, 502i, 503, 505, 601, 605, 605a, 609, 702, 703, and 704
". . . to ensure retaining a community of individuals competent in practicing the [criticality] control."	All experiments and experimental programs, specifically 507 and 508 - training
". . . experiments targeted at the major sources of discrepancy between the theory and the experiments . . ."	101, 102, 304, 606, and 707

II. ENIWG Operations

The function of the Workgroup is to provide the criticality community with a hierarchy of experiments needed to support U.S. DOE contractor operations. At the beginning of a new DOE program or modification to an existing program that involves fissile material, the ENIWG makes an evaluation to determine if current criticality benchmarks are adequate. If these benchmarks are found to be inadequate, a new criticality experiment may be necessary for safety and/or economic reasons. If such an experiment is indeed required, then a listing will appear in this document.

Identifying Experiments and Experimental Programs. Experimental Programs delineate general representations of a broad experimental need (i.e., dosimetry). Experiments are more specific in nature.

For each experiment and experimental program identified by the Workgroup, the requester or sponsor provides a justification statement (see form in App. C). This justification information is used to evaluate the need for the experiment and should (1) discuss existing criticality data (if any) and why it is deficient; (2) provide a description of the needed experiments; and (3) list potential benefits.

At the beginning of each experiment and experimental program listing the following general information is given: (1) the DOE contractor who needs the experimental data; (2) the experiment or experimental program category; and (3) the application of the experiment or experimental program.

Rating Experiments and Experimental Programs. Experiments and experimental programs are rated by representatives from the ENIWG who have determined the priority listing for each entry. These representatives also consider the identification of a sponsor and the extent to which such experiments will support programmatic needs or provide basic physics data.

In addition, a subcommittee has been formed of the Weapons Criticality Committee to identify the needs and priorities of nuclear safety experiments that are nuclear-weapons specific. This effort will be coordinated with the Workgroup.

II. ENIWG Operations

Rating Experiments and Experimental Programs (continued).

Each experiment and experimental program listed in the document has a *priority* listing that is one of the following: (1) Maximum practical attention; (2) Required for new or ongoing DOE operation; or (3) Less urgent than priority (2).

The *status* ranking of each experiment and experimental program is designated as one of the following: (1) Initial Request, (2) Justification Completed, (3) Justification Being Prepared, (4) Experiment Identified, (5) Anticipated Need, (6) Experiment in Progress, or (7) Experiment Complete.

Note that *status* and *priority* are different and can differ for any single experiment and experimental program. However, every effort should be made to bring them to an equivalent level so that, for instance, the highest priority experiments should also be the ones closest to completion.

Summary Listing of Experiments and Experimental Programs and Their Priorities. Table II lists the 59 experiments and experimental programs that have been identified and prioritized. The 21 experiments considered highest priority (maximum practical attention) are listed in Table III.

Table II: Identified and Prioritized Experiments and Experimental Programs.

		Number of Priority		
Categories		Priority 1	Priority 2	Priority 3
Highly Enriched Uranium	(HEU)	2	5	0
Low-Enriched Uranium	(LEU)	2	5	1
Plutonium	(P)	4	1	0
Plutonium/Uranium Fuel	(PUF)	0	1	2
Transportation/Applications	(T/A)	9	8	0
Baseline Theoretical	(BT)	6	2	4
Criticality Physics	(CP)	1	5	1
Total	(59)	24	27	8

New Transportation/Applications Category. This new subset of criticality experiments is intended to cover the areas of storage, transportation, waste, dosimetry alarm systems, training, emergency response, processing, and regulations and standards. The material is divided into two parts—Programs and Specific Experiments. The program areas are further subdivided into specific experiments where appropriate.

It is assumed that the physical facilities of the critical mass laboratories are "User Facilities." These facilities would be maintained to support experimental capability, and are made available to experimenters. Of course, the permanent facility staff would maintain the capability to conduct experiments, or to supervise the temporary staff for particular experiments.

Table III: Highest Priority Experiments and Experimental Programs.

Category	Experiment	Experimental Program or Experiment Title
HEU	104	Advanced Neutron Source
	106	TOPAZ-II Reactor
LEU	206	Sheba Reactivity Parameterization
	207	Sheba Reactivity Void Coefficient
P	301	Plutonium Solution in the Concentration Range from 8 g/L to 17 g/L
	303	Effectiveness of Iron in Plutonium Storage and Transport Arrays
	304	Plutonium with Extremely Thick Beryllium Reflection
	306	Arrays of 3-kg Pu-Metal Cylinders Immersed in Water
T/A	501	Assessment for Materials Used to Transport and Store Discrete Items and Weapons Components
	Program 502	Waste Processing, Transportation, and Storage
	502c	Validation of WIPP Hydrogen Generation Calculations
	502h	Minimum Critical Mass of Fissile-Polyethylene Mixture
	502i	Criticality Studies that Emphasize Intermediate Energies
	Program 503	Validation of Criticality Alarms and Accident Dosimetry
	Program 504	Accident Simulation and Validation of Accident Calculations
	Program 505	Evaluation of Measurements for Subcritical Systems
	508	Development of a Demonstration Experiment
BT	601	Critical Mass Experiments for Actinides
	606	Plutonium with Extremely Thick Beryllium Reflection
	607	Establishing the Validity of Neutron-Scattering Kernels
	608	Extending the Standard ANSI/ANS 8.7 to Moderated Arrays
	609	Fission Rate Spectral Index Measurements in Three Assemblies
	610	Validation of Calculational Methodology in the Intermediate Energy Range
CP	702	Spent Fuel Safety Experiments (SFSX)

II. ENIWG Operations

New Transportation/Applications Category (continued).

Training would be included as part of continuing capability. The training is divided into three parts. Training is provided to those who operate the critical experiments, which is the first part. The second part is a continuation and expansion of the nuclear-criticality-safety hands-on, 2-, 3-, and 5-day training courses that have been provided for several years. The third type of training is an "intern-in-residence" program to allow personnel an opportunity to gain experience in the day-to-day operation of a critical experiment facility. An important adjunct of the training program is developing a simulator to demonstrate the characteristics of critical systems. We proposed that this development becomes a "catalog" item under the auspices of the DOE and that this simulator is made available to contractors and others at cost.

Programs and experiments included in this category are identified in Table IV.

Table IV. New Transportation/Applications Experiments and Experimental Programs.

Experiment 501:	Assessment for Material Used to Transport and Store Discrete Items and Weapon Components.	Priority 1
Experimental Program 502:	Waste Processing, Transportation, and Storage.	Priority 1
Experiment 502a	Absorption Properties of Waste Matrices	Priority 2
Experiment 502b	In Situ Drum Stacking	Priority 2
Experiment 502c	Validation of WIPP Hydrogen Generation Calculations	Priority 1
Experiment 502d	The In-Tank Precipitation (ITP) Process for ^{235}U	Priority 2
Experiment 502e	The In-Tank Precipitation Process for $^{235}U + ^{239}Pu$	Priority 2
Experiment 502f	The In-Tank Precipitation Process for ^{239}Pu	Priority 2
Experiment 502g	Determination of Fissionable Material Concentrations in Waste Materials	Priority 2
Experiment 502h	Minimum Critical Mass of Fissile-Polyethylene Mixture	Priority 1
Experiment 502i	Criticality Studies That Emphasize Intermediate Energies	Priority 1
Experimental Program 503:	Validation of Criticality Alarms and Accident Dosimetry.	Priority 1
Experimental Program 504:	Accident Simulation and Validation of Accident Calculations.	Priority 1
Experimental Program 505:	Evaluation of Measurements for Subcritical Systems.	Priority 1
Experiment 506:	Safe Fissile Mass Thresholds for an Array of Waste Storage Drums.	Priority 2
Experimental Program 507:	Simulator Development	Priority 2
Experiment 508:	Development of a Demonstration Experiment	Priority 1

III. Resources and Status of Facilities

The current (1994) status of available critical facilities and their resources are listed below. Although several facilities have been closed, they are listed here for historical reasons. Included in the description of each facility are the:

- core technical capabilities (that is, what assemblies, or test cells, and what materials are available for experiments);
- current documentation (for example, SARs, TSRs, and operating procedures); and
- personnel resources.

A. LACEF

1. Core Technical Capabilities. The mission of the Los Alamos National Laboratory (LANL) is:

> "The Los Alamos National Laboratory is dedicated to applying world-class science and technology to the nation's security and well being. The Laboratory will continue its special role in defense, particularly in nuclear weapons technology, and will increasingly use its multidisciplinary capabilities to solve problems in the civilian sector."
>
> – S. Hecker (1993)

Operating at Pajarito Site since 1946, the Los Alamos Critical Experiments Facility (LACEF) has been actively involved in this mission. Much of the original nuclear criticality research was performed at this site, and the facility continues to house the most significant collection of critical assemblies in the Western Hemisphere. The LACEF consists of three remotely controlled laboratories, known as kivas, which are located approximately one-quarter mile from the main building that houses the individual control rooms for each kiva. The assemblies in the kivas are described below. The combination of the assemblies, a large inventory of fissile material, and structural materials makes the LACEF one of the most diversified facilities for the simulation of nuclear reactors, weapons, and process applications; it is also a resource for performing research for the nuclear community.

Assemblies. The assemblies that may be operated at LACEF (see Table V for those currently available) can be subdivided into four categories:

1. Benchmark assemblies are stable, definable configurations containing precisely known components. They can have interchangeable or adjustable fissile cores and reflectors.
2. Assembly machines are general-purpose platforms into which fissile, moderating, reflecting, and control components can be loaded for short-range study of the neutronic properties of the materials.
3. Solution assemblies are specifically designed to allow critical operations with configurations containing fissile solutions.
4. Experimental reactors are either cooled naturally or by self-contained heat rejection systems and may be operated for a significant time at low-power levels.

2. Current Documentation and Personnel Resources. The LACEF staff is trained and certified and documentation is current.

Table V. Critical Assemblies at the LACEF.

Assembly	Type	Applications
Big Ten	Large, fast-spectrum, steady-state benchmark assembly	1, 2, 3, 4
Comet	General-purpose, vertical assembly machine (portable)	2, 5, 6
Flattop	Fast-spectrum, steady-state benchmark assembly	1, 5, 6
Godiva IV	Fast-burst assembly (portable)	1, 2, 4, 6, 7, 8
Honeycomb	Large, general-purpose, horizontal assembly machine	5, 9, 10
Mars	Large, general-purpose, vertical assembly machine	3, 5, 6
Planet	General-purpose vertical assembly machine	2, 5, 6
Sheba	Liquid, steady-state and burst assembly	1, 2, 4, 7, 8
Skua	Annular-core fast-burst assembly	1, 2, 7, 8
Venus	Large, general-purpose machine (used for solutions)	1, 4, 5, 6, 8

Applications Legend

1. Irradiation studies
2. Neutron/gamma transport effects
3. Nuclear fuel development
4. Detector development studies
5. Critical mass and separation studies
6. Criticality safety training
7. Vulnerability, lethality, and countermeasures (VL&C)
8. Criticality alarm development
9. NEST & START technique development
10. Weapons safety study

III. Resources and Status of Facilities (continued).

B. Area V, Sandia National Laboratories (SNL)

1. Core Technical Capabilities. Area V at Sandia National Laboratories (Albuquerque) comprises numerous research and test laboratories whose main activities center upon research work conducted at versatile reactors and gamma-ray source facilities. The main components of Area V are the Annular Core Research Reactor, the Sandia Pulse Reactor II, the Sandia Pulse Reactor III, the Gamma Irradiation Facility, the Hot Cell Laboratory (Glove Box Laboratory and Analytical Laboratory), and the Radiation Metrology Laboratory.

Assemblies.

1. The Annular Core Research Reactor (ACRR) is a pool-type research reactor capable of steady-state, pulse, and tailored-transient operation. The reactor was designed to accommodate a 21,000-cm^3 experimental package in a high-flux, near-uniform radiation field. In addition, it has two interchangeable, fuel-ringed external cavities, an unfueled external cavity, and two neutron radiography facilities.
2. The Sandia Pulse Reactor II (SPR-II) is a bare, fast-burst, unreflected and unmoderated-core reactor capable of pulse and limited steady-state operation. It has a small central cavity and is used primarily for narrow-pulse, high-dose-rate testing.
3. The Sandia Pulse Reactor III (SPR-III) is a bare, fast-burst, unreflected and unmoderated-core reactor capable of pulse and limited steady-state operation. The primary experiment chamber is a large central cavity that extends through the core. SPR-III is used for high-neutron-fluence or pulsed, high-dose testing.
4. The kiva that houses the SPR reactor has also been used for the CX experiment recently. This critical assembly was used to perform experiments in support of the Space Thermal Propulsion program.

2. Current Documentation and Personnel Resources. The SNL staff is trained and certified and documentation is current.

C. Argonne National Laboratories (West)

1. Core Technical Capabilities. The Zero Power Physics Reactor (ZPPR) is a modern, world-class critical facility capable of full-scale simulation of fast-spectrum reactors. ZPPR has the flexibility necessary to accommodate critical assemblies for a wide range of reactor types, from very small space reactors to the largest, fast reactors. The facility design makes it possible not only to perform measurements, but also to switch rapidly from one reactor to another. ZPPR's inventory of critical experimental materials is irreplaceable and immense. This is due to the cost of specialized materials for the facility and nonexistent manufacturing capability.

The ZPPR facility, located at the Idaho site of Argonne National Laboratory (ANL), consists of a reactor cell, a fuel-element loading room, a control room, a materials storage building, and workshops. The reactor cell and loading room are situated under a large earthen mound that provides a stable experimental environment and effective safeguards.

2. Current Documentation and Personnel Resources. Last active in March of 1992, the ZPPR facility is presently in nonoperational standby. The documentation is not current. The staff is no longer certified and has been reduced to three personnel.

III. Resources and Status of Facilities (continued).

D. Hanford Laboratories

The Hanford Critical Mass Laboratory was shut down at the end of December 1988; it is no longer functional as a critical facility.

The majority of the world's safety data on criticality of plutonium-bearing solutions was from this facility.

E. Oak Ridge National Laboratory (ORNL)

1. Core Technical Capabilities. Located on the South Boundary of Y-12, Building 9213 housed the critical facility at ORNL. The facility, which was operational between 1950-1975, contained three cells: one was equipped to perform solution critical experiments, and the other two were equipped to perform solid critical experiments on split tables.

2. Current Documentation and Personnel Resources. The facility has been shut down. There is no trained and certified staff and no current documentation.

F. Rocky Flats

1. Core Technical Capabilities. The Rocky Flats Critical Mass Laboratory (CML) is currently in a standby mode. The facility is gradually being defueled, decontaminated, and decommissioned. This process is not completed.

The CML has one test cell that is large and well equipped with versatile handling equipment. It is thick walled and has a history of a very low leak rate from intentional over pressurization. The interior atmosphere can be completely isolated during an experiment. These properties make the test cell ideal for the safe performance of critical experiments.

Assemblies. This test cell contains four assembly machines, two of which are a vertical split table and the "liquid-reflector apparatus." The former has never been used and cannot be operated without major repairs; the latter was dismantled in the 1980s, pending rebuilding using a more efficient design, but this has not yet occurred. The other two assemblies are still present and fully operational:

- The "horizontal split table" is a large assembly capable of being loaded to many tons. Its separation parameters can also be precisely controlled and accurately measured.
- The "Solution Base" is an assembly that is still connected to a uranium solution tank farm that contains 560 kg of high-enriched uranyl nitrate solution in 2700 L of solution. The solution is quite free of impurities and exists at an ideal acid normality. Two concentrations are housed: one is approximately the minimum-critical-volume concentration; the other is ~120 g/L of uranium. The uranium is enriched to about 93% ^{235}U.

2. Current Documentation and Personnel Resources. Documentation for this facility is not current; it has neither an SAR nor any procedures. The staff has been reduced to one person who has been a part of this facility since its construction in 1964; however, he is no longer certified. He is approaching retirement age but plans to continue living in the area and will be available if needed.

IV. Conclusions

At the July 1993 meeting, there was broad representation from DOE contractors, DOE program offices, research reactor facilities, and critical mass laboratories.

This group successfully prioritized the set of experiments, ongoing and new, that were submitted by the U.S. nuclear communities and established the status of each proposed experiment.

Experimental Categories. Evidence presented at this meeting shows the overwhelming need for a wide variety of critical experiments (refer to Table I). Some conclusions that can be drawn from the information presented here include the following:

1. The majority of Priority-1 experiments and experimental programs (9) are in the Transportation/Applications category, with the Baseline Theoretical and Plutonium categories having 6 and 4 Priority-1 experiments and experimental programs, respectively.

   Note: Currently, there are no funded experiments in these three categories. Nor is there a facility that is currently open which is capable of performing plutonium solution experiments.

2. Criticality safety training is recognized as one of the most important aspects of maintaining our technical capability.

3. The new priorities for needed experiments reflect the change in the mission of the DOE and the current thinking in the nuclear community, as well as continued experiments that are recognized as supporting U.S. processing facilities.

4. A concerted effort has been made to integrate Physics Criteria for the Benchmark Critical Experiments document (see App. D) into this forecast.

5. An important activity that arose from the meeting was to create an initial draft of criteria for establishing areas of applicability (see App. E).

Resources and Status of Facilities. Currently, there is only *one* general-purpose critical facility that remains open: the Los Alamos Critical Experiments Facility. Sandia National Laboratories (Albuquerque) has research reactors and the capability to perform small critical experiments in their kiva; however, there is no capability to perform solution critical experiments.

Rocky Flats CML is currently on standby status.

Future Directions. There is an overwhelming need for critical experiments to be performed for basic research and code validation. The Workgroup will continue to work with the changing direction of the DOE and the nuclear community to identify experiments and prioritize them.

Department Needs for Criticality Research in Support of Various Programs

R. Walston, DOE/AL/SPD

I. Introduction

The department is facing downsizing. The weapons program is being downsized. The budget is being downsized. Future technologies are in their infancy. The question of support for a nuclear criticality facility comes at a time when nuclear energy, nuclear education, and nuclear technology is on the downswing in the U.S.; proliferation, nuclear energy, and technological competition are on the upswing in other countries. Nuclear material inventories will increase significantly. Of necessity, one is forced to speculate on the need, merit, and nature of future critical experiments and the need of a dedicated facility in support of the nations' weapons development and nuclear technology role.

II. DOE Critical Facilities

The DOE critical facilities have historically been a source of critical mass data, cross sectional data, new core criticals, prompt reactor data, and vital criticality training for the nation. A DOE critical facility provided the interaction with the British, Canadian, French, Japanese, Mexican, Russian, and various university scientists over the years. DOE critical facilities have historically been the most significant creators of safety information and sources of nuclear technology transfer. It will be a DOE facility that maintains the technological core competency for the nation's nuclear criticality analysis.

DOE nuclear criticality facilities have the unique ability to perform classified and unclassified research by drawing on the support of other DOE facilities such as Sandia National Laboratories simulation facilities, Nevada Test Site, Phermix at LANL, and other sites. Only DOE facilities are allowed to have plutoniums, actinides, highly enriched uraniums, and other such materials.

The loss of a nuclear criticality facility (the remaining one) would of necessity imply the relocation of material and personnel. Should the need arise for a nuclear critical experiment, it could be particularly difficult to reassemble the equipment and personnel, especially if it were a classified experiment. It could take several years to resume operation, depending on how long the facility had been secured. It may become necessary to purchase our criticality data from the Japanese, for example.

III. DOE Needs for Nuclear Data and Criticality Information

The following list is a projection of the Department's needs with respect to nuclear data and criticality information as it relates to nuclear safety and the need for a criticality research facility:

A. Safety, Training, and Code Validation

1. Hands-on training for the department's fissile material workers and oversight personnel will continue to be needed to assure safe operations at many of the department's facilities. This training creates considerable nuclear safety inquiry within nuclear facilities.

2. Nuclear data on super prompt criticals for thermal and fast configurations is important to the department's safety database. Considerable amount of new research is needed in this area to assure safe operations.

3. Neutron and gamma burst and steady state machines are needed to test and validate various criticality detector systems within the department.

III. DOE Needs for Nuclear Data and Criticality Information

A. Safety, Training, and Code Validation (continued)

4. The nuclear criticality community has many desired experiments to replace extrapolated or sketchy data with validated experimental data.

5. A total weapons test ban may require alternate methods to verify relevant nuclear data for safety and reliability.

6. A critical facility would support emergency analyses for accident scenarios within the department (for example weapons, reactor accidents, or NEST-type events). Analysis of East Block material storage and handling is anticipated. Support for nuclear nonproliferation activities must be available.

B. New Fuels and Reactor Core Designs

1. New fuels (for example particle bed-type fuels) are being considered for space propulsion systems. Data leading to nuclear safety must come from modeling and experiments with fuel configurations in a core, and particle distributions representing accident-caused dispersions of particles.

2. New fuels and coolants will operate over temperature ranges from cryogenic temperatures to possibly several thousand degrees Kelvin in the nuclear propulsion reactor. Basic cross-sectional data for cryogenic hydrogen, for example is not thoroughly developed but is important in the nuclear safety and design of the core. Very little physics data exist on materials at very low temperatures.

3. Exploration of fissile material configurations, other than configurations "at critical," is needed to achieve nuclear data for safe design. The dynamics of solution criticals and excursions are not well understood and should be explored.

4. New reactor-core nuclear data will be needed. New reactivity exploration will be needed. The Oak Ridge "Advanced Neutron Source" is such an example. The most recent example is the CX at Sandia National Laboratories.

5. Alternate uses of plutonium (plutonium-based reactors) driven by stockpile reductions and control may require plutonium criticality analyses in support of safety and design of processing equipment and fuel development.

6. Nuclear safety data may be needed for compact auxiliary-power reactors used in space exploration, such as the SNAP type cores, and the accident environments they could be subjected to as potential plutonium burners.

C. Waste Processing and Storage

1. The weapon downsizing programs in the U.S. (and the East Block) will produce unknowns in storage arrays, including the spacing of various units in potentially hostile environments (for example, flooding, fire, etc.).

2. Critical mass data for many of the transuranics and actinides is limited. Some of these elements have large fission cross sections, some have threshold fission energies, and others have combinations of both characteristics. Many of these elements will become abundant and of concern if spent-fuel processing resumes.

III. DOE Needs for Nuclear Data and Criticality Information

C. Waste Processing and Storage (continued)

3. Pressure will exist for compacting wastes that contain fissile material, while at the same time preserving nuclear safety. The threshold value for economic recovery will go up, thus increasing fissile materials in nuclear wastes. Nuclear criticality for large arrays is not well understood.

It is anticipated that other criticality related information will be desired as the country moves forward into space missions, new reactor concepts, and new methods for dealing with safety. In addition, the department must consider that the "critical facility concept" provides an avenue for a collection of materials and experts who will provide inquiry and expertise for safety issues as they arise, and will be the center of focus for any nationally and internationally related data creation and exchange.

IV. The Need for a Critical Facility

In the past, several critical facility laboratories existed within the department to explore fissile material configurations in support of specific activities, for example plutonium parts fabrication, fissile material recovery processes, etc. For most of these facilities, the original mission has been canceled or moved and the critical facility laboratory has been decommissioned.

A critical facility typically operates with core configurations at zero power, versatile fuel configurations, little or no heat removal, and minimal fission product controls. These systems lend themselves to the ease of physics data acquisition and system change to accommodate experimental needs. The technical safety requirements and safety analysis report typically reflect generic issues and limitations, as opposed to specific reactors. Independent review, oversight, training, and configuration control is unique for these types of facilities. Only DOE's Defense Programs have this breadth of facility technology and criticality knowledge in the United States.

V. Conclusion

A report was produced in May 1987 "FORECAST OF CRITICALITY EXPERIMENTS NEEDED TO SUPPORT U.S. DOE CONTRACTOR OPERATIONS 1987-1992" (DOE/NCT-03) by members of the criticality research community. It suggests a variety of critical experiments that would support enhanced safety or efficiency in operations, transportation, storage, and analysis. However, they could not have anticipated the massive changes that would occur in the national and international situation with regard to weapons, nuclear power, or space exploration. A few of the experiments have been carried out, but most of the facilities have been decommissioned.

Department of Energy Criticality Safety Program: Qualified Analytical Methods and Nuclear Data

R. Westfall, Oak Ridge National Laboratory

I. Recommendation 93-2

In its Recommendation 93-2 to the Secretary of Energy (Appendix B), the Defense Nuclear Facilities Safety Board recognizes as a principal ingredient of nuclear criticality control the "theoretical understanding of neutron multiplication processes in critical and subcritical systems, leading to predictability of the critical state of a system by methods that use theory benchmarked against good and well characterized critical experiments." In this regard, DOE Order 5480.24, NUCLEAR CRITICALITY SAFETY, incorporates as basis elements and control parameters for its contractor criticality safety programs the requirements of six ANSI/ANS nuclear criticality safety standards. The principal standard dealing with the use and qualification of analytical methods is ANSI/ANS 8.1, "Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors."

II. Paragraph 4.3

Paragraph 4.3 of this standard admits a wide variety of methods for predicting effective multiplication factors or for deriving subcritical limits. However, a common procedure for establishing the validity of these methods is specified in paragraphs 4.3.1 through 4.3.6. To implement this standard, the nuclear criticality safety community, primarily through the DOE Nuclear Criticality Technology and Safety Project, has initiated several efforts. Under this project, the Nuclear Criticality Methods Resource Center has developed and enhanced criticality methods, as well as provided training in the use of the computational software. The concept of criticality methods development being performed on a DOE-wide basis has been very useful and cost effective. However, it should be expanded to include the full range of software required for systems analyses, nuclear data preparation, and sensitivity analyses. Also, the objective of providing redundant capabilities developed with independent approaches should be pursued. This objective is consistent with the Double Contingency Principle employed widely in criticality safety practice.

III. Paragraphs 4.3.1 through 4.3.6

Paragraph 4.3.1 of ANSI/ANS 8.1 deals with establishing analytical biases in the calculation of effective multiplication factors (k_{eff}). The primary tools for calculating k_{eff} and supported by the Resource Center are the KENO codes, developed at ORNL, and the MCNP codes, developed at LANL. They both employ the Monte Carlo method to exploit its flexibility in treating complex material-geometry systems. However, the two codes have substantially different geometry treatment schemes and neutron kinematics, KENO being an energy multigroup code and MCNP being an energy pointwise code. Thus the pair of codes provide the independent, corroborative capability required for a successful program. Deterministic neutron transport methods are very useful for establishing the analytical bias. Free of the statistical uncertainty associated with Monte Carlo analyses, these techniques yield closed-form solutions for the neutron flux throughout fissile material systems. The Resource Center has supported the use of deterministic transport methods at ORNL (XSDRN, DORT/TORT) and LANL (TWODANT/THREEDANT) in the processing of multigroup cross sections and in studying reaction rates. In the case of second-order accuracies, deterministic methods must be applied to determine the contributions to analytical bias. In addition to k_{eff}, several

III. Paragraphs 4.3.1 through 4.3.6

Paragraph 4.3.1 of ANSI/ANS 8.1 (continued).

reactor physics parameters are useful for this purpose. They are listed in the Physics Criteria for Benchmark Critical Experiments, Appendix D. In addition to providing validation for specific applications, critical experiments should be performed to provide this basic physics information. The proposed Experiments 206 and 208 are of this nature. Finally, the analytical biases are dependent on both the neutron transport methodologies and the cross-section data. Support of neutron processing software such as the AMPX system at ORNL and the NJOY system at LANL should be put on an ongoing basis.

Paragraph 4.3.2 of ANSI/ANS 8.1 addresses the issue of the application range for qualifying critical experiments designed to validate the analyses of specific systems. Heretofore, this issue has been treated primarily by professional judgment. A rudimentary effort to define criteria for matching experiments with fissile systems is included here as Appendix E. The DOE Criticality Safety Program should support the testing and refinement of these criteria. An effective set of criteria for establishing the range of applicability would be of great value to the criticality safety community.

Paragraph 4.3.3 addresses the concept of the safety margin, including the analytical bias and various areas of uncertainty. The criticality safety community has generally adopted this concept rather than always adhering to a single criterion for subcriticality ($k_{eff} \leq 0.95$). The safety margin concept justifies economies and, in some instances, provides more effective margins of safety. The DOE should support the development of uncertainty-sensitivity methods for enhancing this process.

Paragraph 4.3.4 addresses the issues of software verification, which is the responsibility of the developing organization, and software configuration control, which is the responsibility of the user. Software verification is an important function performed by the Resource Center. It would greatly benefit from more varied and accurate measurements of physics parameters, as discussed above.

Paragraph 4.3.5 of ANSI/ANS 8.1 states that "Nuclear properties such as cross sections should be consistent with experimental measurements of these properties." Towards this end, the DOE Criticality Safety Program should make more effective use of the Evaluated Nuclear Data Files developed by the nuclear data community and formally tested by elements of the Cross Section Evaluation Working Group (CSEWG). Heretofore, CSEWG data testing has been primarily in the areas of fast reactors, thermal reactors, and radiation shielding. This data testing should be extended to the broad range of nuclides and material compositions of interest to nuclear criticality safety. Substantial benefit would accrue to the DOE Criticality Safety Program from its involvement with CSEWG data testing procedures, including the use of uncertainty-sensitivity techniques. Results from this activity would include the justification for lower uncertainties in measured data and, ultimately, more accurate criticality analyses and reduced analytical biases.

Paragraph 4.3.6 addresses the elements of validation studies that should be documented. Documentation of software verification and the performance of cross-section libraries should continue as important functions of the Resource Center.

IV. SUMMARY

In summary, the DOE Criticality Safety Program, under the Nuclear Criticality Technology and Safety Project, has made substantial progress in providing both analytical software and measured data. However, this effort should be expanded to include the full range of software required for systems analyses, nuclear data preparation, and sensitivity analyses. An overall objective should be the provision of redundant capabilities developed with independent technical approaches.

Acronyms

ACRR	Annular Core Research Reactor
AEC	Atomic Energy Commission
AMPX	neutron processing software at ORNL
ANL	Argonne National Laboratory, University of Chicago
ANSI/ANS 8.1	American National Standards Institute/American Nuclear Society Standard 8.1, "Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors"
ANSI/ANS 8.7	ANSI/ANS Standard 8.7, "Guide for Nuclear Criticality Safety in the Storage of Fissile Materials"
APRFR	Air Force Pulse Reactor
AVLIS	Advanced Laser Isotope Separation Program
B & W	Babcock and Wilcox Company
BNFL	British Nuclear Fuels, Ltd.
BNL	Brookhaven National Laboratory
BWR	boiling water reactor
CAI/DOE-RFO	M. S. Chew and Associates, Inc./Rocky Flats Operations Office
CML	critical mass laboratory
CMPO	octylphenyl-N,N-disobutylcarbamethylphosphine oxide
CNPS	Compact Nuclear Power Source
CNR	Center for Neutron Research
CSEWG	Cross Section Evaluation Working Group
CX	Critical experiment at Sandia National Laboratories
DC	delayed critical
DNFSB	Defense Nuclear Facility Safety Board
DOE	Department of Energy
DOE-HQ	Department of Energy Headquarters
DOE-TIC	Department of Energy Technical Information Center
DOE/AL/SPD	Department of Energy, Albuquerque Operations Office, Special Projects Division
DORT/TORT	ORNL deterministic transport code for neutron cross sections
EBR-II	Experimental Breeder Reactor II
EG&G	Edgerton, Germeshausen, and Grier, Inc.
EM-30	WIPP site
ENCOG	Experimental Needs Coordinating Group
ENIWG	Experimental Needs Identification Workgroup
ERDA	Energy Research and Development Agency

FAST	Fluorinal and Storage
FERMCO	Fernald Environmental Management Co.
FFR	Fast Fission Ratio
FFTF	Fast Flux Test Reactor
FWHM	full width at half maximum
GDP	gaseous diffusion plant
HE	high explosive
HEU	highly enriched uranium
HPRR	Health Physics Research Reactor
ICPP	Idaho Chemical Processing Plant
INEL	Idaho National Engineering Laboratory, EG&G Inc.
ITP	in-tank precipitation
KAPL	Knolls Atomic Power Laboratory
KENO	Computer code for k_{eff} at ORNL
LACEF	Los Alamos Critical Experiments Facility
LACEF/SHEBA	Los Alamos Critical Experiments Facility/Solution High-Energy Burst Assembly
LACEF/SNL	Los Alamos Critical Experiments Facility/Sandia National Laboratories – Area V
LANL	Los Alamos National Laboratory, University of California
LET	linear energy transfer
LEU	low-enriched uranium
LLNL	Lawrence Livermore National Laboratory, University of California
LWR	Light Water Reactor
LYNER	Low Yield Nuclear Explosive Research
MCM	minimum critical mass
MCNP	Monte Carlo n-particle (code)
MIT	Massachusetts Institute of Technology
MMES	Martin Marietta Energy Systems at ORNL
MRS	monitored retrieval storage
NCIS	Nuclear Criticality Information System
NCT&SP	Nuclear Criticality Technology and Safety Project
NE213	Nuclear Enterprize-213 (detector)
NEST	Nuclear Emergency Search Team
NEST & ARG	Nuclear Emergency Search Team & Accident Response Group
NIST	National Institute of Standards Technology
NPR	New Production Reactor

NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory, MMES
OSTT	Office of Scientific and Technical Information
PHERMEX	Pulse High-Energy Machine Emitting X-Rays, LANL
PNC	Power Reactor and Nuclear Fuel Development Corporation
PNL	Battelle—Pacific Northwest Laboratory
PVC	polyvinylchloride
PWR	pressurized water reactor
QA	quality assurance
R	roentgen, unit of exposure
RBE	relative biological effectiveness
RCR	Relative Conversion Ratio
RF CML	Rocky Flats, Critical Mass Laboratory
RFP	Rocky Flats Plant
SAR	Safety Analysis Report
SFSX	Spent Fuel Safety Experiments
SIS	special isotope separation
SNAP	Systems for Nuclear Auxiliary Power
SNL	Sandia National Laboratory
SNM	Special Nuclear Material
SPD	Safety Programs Division
SPR-II	Sandia Pulse Reactor-II
SPR-III	Sandia Pulse Reactor-III
SRL	Savannah River Laboratory
SRP	Savannah River Plant, Westinghouse Company
SRS	Savannah River Site
START I & II	Strategic Arms Reduction Treaty I and II
TRU	transuranic waste
TRUEX	transuranic extraction
TSR	Technical Specification Requirements
TWODANT/ THREEDANT	LANL deterministic transport code for neutron cross sections and reaction rates
UKAEA	United Kingdom Atomic Energy Authority
VL&C	vulnerability, lethality, and countermeasures
WHC	Westinghouse Hanford Company
WINCO	Westinghouse Idaho Nuclear Company
WIPP	Waste Isolation Pilot Plant

Forecast of Criticality Experiments: Acronyms

WMCO	Westinghouse Material Company of Ohio
WPPS	Washington Public Power System
WSMR	White Sands Missile Range
WSRC	Westinghouse Savannah River Company
XSDRN	ORNL deterministic transport code for neutron cross sections
Y-12 Plant	Oak Ridge Y-12 Plant
ZPPR	Zero Power Physics Reactor

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Criticality Experiments Needed to Support Highly Enriched Uranium Operations

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Criticality Experiments Needed to Support Highly Enriched Uranium Operations

Experiment 101
U(93) Metal Reflected by Annealing Salts

Contractor Requiring Data	Y-12 Plant (Martin Marietta Energy Systems)
Category	Highly enriched uranium
Application	Provide basic safety information to enhance the process of nuclear criticality safety analysis
Rating — **Status**	Justification completed
Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed

For highly enriched uranium metal working operations at the Oak Ridge Y-12 Plant, it is necessary to immerse individual units in a mixture of salts (sodium carbonate, potassium carbonate, and lithium carbonate) at elevated temperature. These salts are also occasionally present in the process area as solids. There is an indication from computational studies that solid sodium carbonate may be a better reflector than water, hence, the frequent assumption of a water reflector may not be conservative. Experiments need to be performed to determine the effectiveness of the individual salts and salt mixtures used as reflectors about highly enriched uranium metal. These experiments could be readily combined with other proposed experiments.

Proposed experimental facility

LACEF

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Experiment 102
Large Array of Small Units

Contractor Requiring Data		Y-12 Plant (Martin Marietta Energy Systems)
	Category	Highly enriched uranium
	Application	Enhance current DOE operation
Rating	**Status**	Justification completed
	Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed

Available experimental data for highly enriched uranium (and plutonium) have: (1) individual units which are relatively massive compared to the actual units that are typically stored; (2) much closer spacing between individual units than the spacing ordinarily encountered in storage; and (3) considerably fewer units in the experimental array compared to the number in typical storage arrays. Monte Carlo nuclear criticality safety codes are validated by comparing the codes with experimental data. Then these codes are used to calculate storage arrays that are characteristically different from the experimental arrays, as described above. There is some concern that the neutron coupling in actual large arrays of relatively small units may be different, hence, less conservative, than the coupling found in the experimental small arrays of relatively large units. This concern applies to uranium and plutonium, both of which will likely require more storage in the future.

These experiments could also be easily combined with other proposed array experiments, such as studies of interunit moderations.

Proposed experimental facility

LACEF, or Rocky Flats (arrays of uranium solutions)

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Experiment 103
Slightly Moderated U(93) Oxide Powder

Contractor Requiring Data		Y-12 Plant (Martin Marietta Energy Systems)
	Category	Highly enriched uranium
	Application	Enhance current DOE operation
Rating	**Status**	Justification completed
	Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed

Past critical benchmarks have included experiments with dry uranium oxide and experiments with uranium in solution. However, critical benchmark experiments with uranium oxide at low moderation (for example, H/X = 1) are not adequate. Potential processing conditions at the Y-12 Plant and Rocky Flats could involve moist uranium oxide. The criticality safety data for such processes must be provided. Critical experiments that involve moist uranium oxide are needed as the basis for critical mass data and as the basis for validating criticality codes for situations involving moist uranium oxide. Such experiments can also be applied to undermoderated systems involving uranium oxide.

Proposed experimental facility

LACEF

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Experiment 104
Advanced Neutron Source

Contractor Requiring Data		Oak Ridge National Laboratory
	Category	Highly enriched uranium
	Application	Support new DOE program
Rating	**Status**	Justification completed
	Priority	Maximum practical attention

Description of operation and experimental data needed

The Advanced Neutron Source reactor program has been authorized by DOE. This will become the largest such facility in the world. The ANS program will develop an ultra-high-flux compact reactor concept to provide a high-intensity, steady-state source of neutrons for research on condensed matter. The preliminary core design consists of a D_2O-cooled and moderated, highly enriched uranium/silicon/aluminum (U_3Si_2/Al) fuel in an offset split core. The D_2O reflector tank will have several beam tubes, cold and hot neutron sources.

A critical experiment program will be needed to support fabrication and subsequent handling and storage of the fuel. Measurements of critical configuration, control rod calibration, fission power density, neutron flux per fission, gamma flux density, temperature coefficient, and reactivity worth measurements in beam tubes are needed to calibrate design computer calculations.

Proposed experimental facility

LACEF/SNL

Contact

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Experiment 105
High-Energy Burst Reactor

Contractor Requiring Data		Los Alamos National Laboratory
	Category	Highly enriched uranium
	Application	Upgrade basis for high-energy burst reactor
Rating	**Status**	Justification completed
	Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed

In the area of neutron fast-burst reactors, the state-of-the-art allows the production of few-tens of microsecond pulses with energy yields approaching 10^{17} to 10^{18} fissions. Much beyond this, uranium metal and currently used alloys melt or fracture. Current weapon technology allows reliable production of low yields in the range of a few tons of yield. Presently, there is little or no experimental measurements of burst reactor behavior in the range up to 50 lbs of yield. The only available data on these systems at such yields come from accident situations, which were not precisely instrumented. Indeed, there are no calibrated computer codes which can calculate the behavior of burst assemblies in this range.

This information is important because the design basis accidents for burst reactor facilities (Godiva-IV, Skua, HPRR, SPR-II, SPR-III, WSMR-Molly-G, and APRFR) is calculated without adequate verification data in the range of interest (10^{18}-10^{19} fissions). Such information would serve as a basis for defining the safety envelopes of the high-energy burst reactor SARs.

Furthermore, the state-of-the-art in burst reactors has reached the limit of current fuel technology. Production of bursts beyond 2 x 10^{17} will require new fuel materials and technology currently not in use.

Specifically, we propose a program of high-energy burst reactor experiments (up to 50 lbs equivalent HE yield) to be performed within a containment sphere. Here, we define high-explosive (HE) equivalent yield as:

Fission yield x (Kinetic Energy/ Total Energy) = HE equivalent yield

10^{17} fissions: 1.4 lb HE x 1% = 0.014 lb HE equivalent

10^{18} fissions: 14 lb HE x 5% = 0.7 lb HE equivalent

10^{19} fissions: 140 lb HE x 10% = 14 lb HE equivalent

(continued)

Description of operation and experimental data needed *(continued)*	The experiments would be performed using a Godiva-class burst assembly that would be incrementally driven to hydrodynamic disassembly with suitable diagnostics to measure yield, initial period, FWHM, fuel state (dynamic pressure and temperature). Extra cores from several current or retired burst machines might be available for such experiments. The site for such a test bed could be LACEF (Kiva III) or the Nevada Test Site (Low Yield Nuclear Explosive Research or LYNER site).
Proposed experimental facility	LACEF, or the Nevada Test Site (LYNER site)
Contact	R. Paternoster Los Alamos National Laboratory P.O. Box 1663, MS J562 Los Alamos, NM 87545 (505) 667-4728; FAX 665-3657

Experiment 106
TOPAZ-II Reactor

Contractor Requiring Data		Los Alamos National Laboratory, Strategic Defense Initiative Office
	Category	Highly enriched uranium
	Application	To increase the safety of the Russian TOPAZ-II space reactor, in support of U.S. Space Reactor Program
Rating	**Status**	Justification completed
	Priority	Maximum practical attention

Description of operation and experimental data needed

The Russian TOPAZ-II space reactor is being modified in the U.S. in preparation for a flight test. The large difference in safety philosophy between the two countries necessitates both modification of the reactor and supportive, credible safety analyses. In order to justify flight testing in the U.S., measurement of the reactor component reactivity-worth measurements are needed for ongoing modifications and safety analyses. By calculation, the TOPAZ-II Space Reactor goes critical in water. The modifications (i.e., redesign of control elements) will alleviate this problem and allow the TOPAZ-II to be launched in this country. Worth measurements would be performed in a TOPAZ-II mock-up assembly at an established critical assembly facility.

Proposed experimental facility

LACEF

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Experimental Program 107
Criticality Evaluations of Space Power & Propulsion Assemblies

Contractor Requiring Data		Sandia National Laboratories
	Category	Highly enriched uranium
	Application	Support new DOE program
Rating	**Status**	Justification completed
	Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed Perform criticality evaluations, control-element reactivity-worth evaluations, and parametric studies (experiments) to characterize proposed and refined designs for nuclear-powered rockets, space power, and propulsion.

Proposed experimental facility LACEF/SNL

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Criticality Experiments Needed to Support Low-Enriched Uranium Operations

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Criticality Experiments Needed to Support Low-Enriched Uranium Operations

Experimental Program 201
SP-100 Surety Program

Contractor Requiring Data	Los Alamos National Laboratory
Category	Low-enriched uranium
Application	Support new DOE program
Rating — Status	Anticipated need. SP-100 program on hold. This experiment description has not been updated to reflect program status.
Priority	Less urgent than priority (2)

Description of operation and experimental data needed

The purpose of the overall program is to develop a safe, compact, light-weight, durable, multi-hundred-kilowatt electric (10 to 1,000 kWe) space reactor (SP-100) and the associated power system technology. The SP-100 reactor core will have 0.33-in.-diam., enriched uranium nitride fuel rods that are cooled by liquid metal. The uranium enrichment will be 50 - 97 wt% ^{235}U. The SP-100 would make possible a broad class of space missions in the mid-1990's and into the next century.

Martin Marietta is responsible for the design and development of the SP-100 reactor. LANL is fabricating the fuel. Initial reactor measurements were made in the ZPPR at the Idaho National Engineering Laboratory, Idaho Falls. Due to funding restrictions and program redirections, technology development has been implemented with an evolutionary strategy. Current program plans do not call for ground testing of the prototypic reactor subsystem. We anticipated that both cold- and warm-critical testing of the flight system reactor will be carried out at the Los Alamos Critical Experiment Facility at LANL. The SP-100 program is currently on hold.

Significant milestones are:

- Phase-I Technology Readiness in early 1995.
- Flight Criticals Testing, which will be determined.

Proposed experimental facility LACEF

Contact

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Experiment 202
Atomic Vapor Laser Isotope Separation (AVLIS)

Contractor Requiring Data		Advanced Laser Isotope Separation Program Project Manager
Category		Low-enriched uranium
Application		Support AVLIS program (The AVLIS program may be privatized. Nonetheless, the need for experimental criticality benchmarks to support the program is recognized here.)
Rating	**Status**	Justification completed
	Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed

Criticality safety design criteria and margins of safety for the AVLIS project will be based on calculational techniques that are invalidated, and for uranium enrichments for which there are no experimental data. Without adequate benchmark critical experiments, there will be a large uncertainty associated with the design criteria parameters. This uncertainty means the margins of safety cannot be sufficiently quantified for particular design criteria.

Critical experiments are needed for code validation purposes. The experiments involve an enriched uranium range of 5 to 10%. Three types of experiments are needed to cover the AVLIS processes:

1. *Homogeneous systems*: uranyl nitrate and uranyl fluoride solutions, and damp uranium oxides, at varying H/U atomic ratios, in reflected and unreflected vessels.
2. *Heterogeneous systems*: uranium metal-water mixtures at various metal-to-water volume fractions and with various metal surface-to-volume ratios.
3. *Arrays*: arrays of interacting vessels with the above materials and with fixed neutron poisons.

Proposed experimental facility LACEF

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Experiment 203
Uranium Fuel Feed Operations

Contractor Requiring Data		Fernald Environmental Restoration Management Corporation
	Category	Low-enriched uranium
	Application	Increase operational flexibility
Rating	Status	Justification completed
	Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed

Margins of safety in production operations are larger than necessary and unduly restrict operational flexibility.

A few critical experiments would introduce three major advantages:

1. Safety margins could be established with more confidence,
2. Storage capacity would be increased significantly in some areas, and
3. Designs of new equipment could be more thorough and complete, because the more flexible computational methods could be used with confidence.

Experimental needs fall into two regions of enrichment and two chemical states. The uranium enrichments range from depleted to 20% ^{235}U. The criticality characteristics of uranium enriched to less than 6-7% ^{235}U is different from more highly enriched uranium in that a moderator must be mixed with the uranium to produce a critical system. For higher ^{235}U enrichments, material can be made critical without the aid of a moderator, although substantial quantities may be required. Two physical states are of interest: water solutions of uranium compounds, and dry metallic (or oxide) systems.

Solution Experiments

1. For the lower enrichment region, a true minimum in critical size or mass exists. Thus, experiments to determine the critical parameters for, say, solutions at 3% and 5% enrichment would be very useful.
2. Given a determination of a critical size at or near the minimum, the change in size (increase) as moderation is increased or decreased is also of interest.

(continued)

Description of operation and experimental data needed *(continued)*

Solution Experiments (continued)

3. In the enrichment range between 6% and 20%, the critical size of the metal system may be smaller than the optimum moderated case. However, the critical size, in the moderation ranges employed in 1 and 2 above, should be determined for this enrichment range also.

Uranium Metal Experiments

The critical mass and size of highly enriched (93.5% ^{235}U) uranium and 30% enriched uranium are well known, but no critical experiment has been performed for uranium enriched to 20%. A critical experiment at or near this enrichment would be very useful for plant operations.

Uranium Metal Pieces in Water

Dissolution (or digestion) of metal scrap has been performed on a regular basis at FERMCO. For slightly enriched uranium, arrangements of solid rods or pieces can have a lower critical mass than the same amount of material as a dissolved compound, or as a metal-water mixture. Thus, experiments with the same enrichment used in A.1., but with uranium of finite-sized pieces (e.g., golf ball size) spaced in a regular array is of special interest.

Proposed experimental facility LACEF or Rocky Flats CML

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Experimental Program 204
Monitored Retrievable Storage (MRS) Facility

Contractor Requiring Data		Oak Ridge National Laboratory
	Category	Low-enriched uranium
	Application	Support new DOE program
Rating	**Status**	Justification completed
	Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed

On March 31, 1987, the DOE submitted to Congress a proposal for a monitored retrievable storage (MRS) facility. Storage capacity for 15,000 metric tons of spent, light-water reactor fuel would be provided. Experiment criticality data in two areas will be needed:

1. Fuel Rod Consolidation

   The MRS will provide the capability to disassemble fuel assemblies and consolidate the fuel rods in storage canisters (for a 2:1 volume reduction). Experimental data will benefit the safety and economics of this operation.

2. Spent-Fuel Burnup versus Reactivity

   DOE Contractors and NRC licensees are interested in obtaining criticality data for spent LWR fuel to confirm calculations. Operational and storage restrictions can be significantly reduced if credit could be taken for burnup. The calculations must account for (1) ^{235}U depletion and fission product formation, which decrease reactivity, and (2) the formation of plutonium, which increases reactivity.

Proposed experimental facility

LACEF

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Experimental Program 205
Effect of Interspersed Moderation on an Unmoderated Storage Array

Contractor Requiring Data		Applicable to all Department of Energy Contractors
	Category	Low-enriched uranium
	Application	Applies to storage arrays of plutonium, HEU, and LEU, where sprinkler systems can introduce water moderation between units.
Rating	**Status**	Justification being prepared
	Priority	Required for new or ongoing operation

Description of operation and experimental data needed

An experiment is needed to provide an experimental benchmark and accurately appraise the effect of introducing low-density water (such as spray from a water sprinkler) into a storage array of unmoderated units of fissile material. Calculations indicate that the water density that produces the highest reactivity depends heavily on the characteristics of the particular system (for LWR fuel rods in water, for example, the highest reactivity appears to occur in the water-density range of 3-5%). This experiment could be conducted in conjunction with another array experiment.

Proposed experimental facility LACEF

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Experiment 206
Sheba Reactivity Parameterization

Contractor Requiring Data		Los Alamos National Laboratory
	Category	Applicable experiment categories
	Application	Enhance current DOE operation
Rating	**Status**	Experiment in progress
	Priority	Maximum practical attention
Description of operation and experimental data needed		This experiment makes the required measurements for the first operations of Sheba. It includes the 1/M initial approach to critical, initial DC operations, and measurements of temperature coefficients, absolute power calibrations, etc.
Proposed experimental facility		LACEF
Contact		K. Butterfield Los Alamos National Laboratory P.O. Box 1663, MS J562 Los Alamos, NM 87545 (505) 667-8944; FAX (505) 665-3657

Experiment 207
Sheba Reactivity Void Coefficient

Contractor Requiring Data	Los Alamos National Laboratory
Category	Applicable experiment categories
Application	Enhance current DOE operation

Rating	**Status**	Experiment in progress
	Priority	Maximum practical attention

Description of operation and experimental data needed

This experiment will attempt to measure the reactivity void coefficient for several regions in Sheba. The first phase is already underway, and consists of calculations using MCNP.

The primary shutdown mechanism in an excursion in a solution system is the introduction of voids due to radiolytic gas formation. The net reactivity effect depends upon the location of the void and the displacement of the free surface. Although it is very difficult to calculate the effects in three dimensions, a better understanding of the reactivity provided by experiment is necessary to model kinetic behavior.

Proposed experimental facility LACEF

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Experiment 208
Benchmark Measurements

Contractor Requiring Data		All Department of Energy contractors
	Category	Applicable experiment categories
	Application	Enhance current DOE operation, compliance with DOE orders to provide QA tools for criticality software
Rating	**Status**	Experiment in progress
	Priority	Required for new or ongoing DOE operation
Description of operation and experimental data needed		The Physics Criteria for the Benchmarks Working Group has generated a list of neutronics observables (Appendix D) that can also be calculated. This proposed series of experiments would try to measure as many of these observables as possible. This effort would help in the certification of computer codes used in criticality safety calculations.
Proposed experimental facility		LACEF/SHEBA
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Criticality Experiments Needed to Support Plutonium Operations

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Criticality Experiments Needed to Support Plutonium Operations

Experiment 301
Plutonium Solution in the Concentration Range from 8 g/L to 17 g/L

Contractor Requiring Data	Westinghouse Hanford Company, Los Alamos National Laboratory, Rocky Flats Plant
Category	Plutonium
Application	Waste handling and storage, low-solution concentration limits
Rating — Status	Justification completed
Priority	Maximum practical attention

Description of operation and experimental data needed

This plutonium concentration range is of interest in the current head-end operation of plutonium processing. These concentration levels are used routinely at LANL, TA-55, and at RFP.

Experimental criticality data is considered to be insufficient to cover the concentration range from 8 to 17 g/L plutonium at H/Pu ratios from 1200 to 2700. The system characteristics for a very large volume (sphere, equilateral cylinder, etc.) means that the location of a reflector outside of this volume becomes vanishingly insignificant as the limiting concentration corresponding to $k_\infty = 1.0$ is reached. Data for one large sphere (4-ft diam) at 9 g/L (H/X=2700) are available, but validation of computer codes at 9 g/L and above 17 g/L appears to give contradictory results with a computational bias appearing to become strongly negative below 20 g/L.

Slab experiments in the 10 to 20 g/L range seem to tie the data points together, but this is not conclusive because of the very different geometries used in the experiment. Cylinder experiments in this range would provide the needed data. Safety of stored waste and waste processing for verification also will require knowledge of criticality in this H/Pu range. Waste programs may also require extension of data for H/Pu ratios beyond 2700 to 3600.

Criticality experiments to verify calculations in the 1200 to 2200 H/Pu range and above will have long-range benefits in applications to head-end plutonium processing, waste storage and processing.

Proposed experimental facility

None available at the present time.

Contact

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Experiment 302
Transuranic Extraction (TRUEX) Process

Contractor Requiring Data	Westinghouse Hanford Company
Category	Plutonium
Application	Support criticality safety evaluations for the TRUEX process at WHC and other DOE sites that may use this process.
Rating — Status	Anticipated need
Priority	Required for new or ongoing operation

Description of operation and experimental data needed A Transuranic Extraction (TRUEX) solvent-extraction process is being developed to support waste vitrification pretreatment. The process removes transuranics from plutonium waste using tri-butyl phosphate as an organic solvent. To assure criticality safety, it is necessary to know how the minimum critical mass of the plutonium-tri-butyl phosphate-CMPO system compares to the plutonium/water system. The need for a criticality experiment is anticipated.

Proposed experimental facility None available at the present time.

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Experiment 303
Effectiveness of Iron in Plutonium Storage and Transport Arrays

Contractor Requiring Data	Westinghouse Hanford Company
Category	Plutonium
Application	Storage and transportation of TRU waste
Rating — Status	Justification completed
Priority	Maximum practical attention

Description of operation and experimental data needed

The effectiveness of the neutron absorption by interspersed iron (or other neutron absorbers) in the container walls in an array increases with increasing neutron leakage from the core fissile material, with all other things (fissile mass, H/X, etc.) being equal. It can cause a pronounced change in the reactivity of the array. Since leakage can vary with both shape and material density, advantage can be taken of this effect to allow for much larger arrays, especially for arrays of loosely distributed material such as wastes in 55-gal drums. Improper cross section selection/preparation can also result in an unsafe calculation of a reactivity that is too low. Since there are no experiments to validate the calculations and since the reactivity effect is so strongly dependent on the above characteristics, it is possible that an unsafe analysis could be made without the analyst realizing how much the accuracy of the result depended on correctly selecting the proper characteristics. Conversely, overly conservative limits on array size could be specified to allow for these uncertainties.

To start these measurements, we will perform a subcritical measurement on a single unit typical of the storage package, and progress to varying concentration, moderation, absorption, and reflection. Array measurements up to a practical limit can be performed as a function of spacing on identical simple elements.

Proposed experimental facility

LACEF

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Experiment 304
Plutonium with Extremely Thick Beryllium Reflection

Contractor Requiring Data		Lawrence Livermore National Laboratory
	Category	Plutonium
	Application	Resolve technical issue
Rating	**Status**	Experiment in progress, part of the experiment is complete
	Priority	Maximum practical attention

Description of operation and experimental data needed

UCRL-5349 reports critical beryllium reflector thicknesses for various masses of α-Plutonium. The results for the most extreme Be reflection of 21-cm and 32-cm thicknesses have long been questioned (and assumed to be in error experimentally) since computations tremendously underpredict reactivity (nonconservative). A recent LANL experiment with about 8.3 cm of beryllium reflection has been performed (Rick Anderson, et al.) with excellent agreement with calculations. Perhaps a source of experimental error could have been made when the data were corrected to ideal spherical configurations. This possibility can only be resolved by locating and reviewing the original experimental notebook or repeating the experiment.

Recommendation: A catalog of experimental notebooks should be compiled for each DOE critical mass facility together with a description of the experiments performed.

Justification: The cost of assembling this information should be small compared to the maintenance and operation of critical facilities. Also, this information would be a tremendous asset to the criticality safety analyst.

Proposed experimental facility

LACEF

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Experimental Program 305
Arrays of 3-kg Pu-Metal Cylinders Immersed in Water

Contractor Requiring Data	Lawrence Livermore National Laboratory
Category	Plutonium
Application	Enhance current DOE operation
Rating — Status	Experiment complete, but not documented
Priority	Maximum practical attention

Description of operation and experimental data needed

A brief description of these completed experiments has been provided by R. E. Rothe, "A Summary of Experiments at the Nuclear Safety Facility, 1965–1990," pp 4-6.

These experiments used the Pu billets from the LLNL Pu array program. The later experimenters (early 1980's) included critical 3 x 3 x 3 arrays immersed in water. None of the experiments were ever published.

Recommendation: These experiments should be formally documented and published. Two of the investigators, R. E. Rothe (RFP) and J. S. Pearson (LLNL), are still available and interested in this project.

Justification: These experiments provide important, basic, criticality safety information regarding moderated Pu arrays. Such data is quite scarce and is useful for computer code validation in applications such as (1) transportation of weapon components, (2) weapon disassembly operations, (3) vault storage, and (4) safe spacing criteria.

Proposed experimental facility LACEF

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Criticality Experiments Needed to Support Plutonium/Uranium Fuel Operations

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Criticality Experiments Needed to Support Plutonium/Uranium Fuel Operations

Experiment 401
Advanced Reactor Design for Metal Fuel (Pu-U-Zr)

Contractor Requiring Data		Westinghouse Hanford Company
	Category	Plutonium/uranium fuel
	Application	Support new DOE program
Rating	**Status**	Justification completed
	Priority	Less urgent than priority (2)

Description of operation and experimental data needed

The DOE has announced plans to concentrate their support for advanced reactor designs that use metal fuel. Past designs have used mixed-oxide fuels.

The plan calls for a new metal fuel for the FFTF reactor and EBR II. Three metal-fuel compositions that need to be evaluated in the FFTF reactor are:

- 90 wt% U (25.2) and 10 wt% Zr
- 82 wt% U (17.5) + 8 wt% Pu + 10 wt% Zr
- 71 wt% U (4.5) + 19 wt% Pu + 10 wt% Zr.

The EBR II test reactor core which is currently 95 wt% U(52) and 5 wt% nonfissile metal, will be changed to 71 wt% U(60) + 19 wt% Pu + 10 wt% nonfissile metal. Criticality experiments are needed to benchmark calculations in support of the fabrication, storage, transportation, and reprocessing of Pu-U metal fuel.

Proposed experimental facility LACEF

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Experiment 402
Mixed Oxides of Pu and U at Low Moderation

Contractor Requiring Data	To be determined
Category	Plutonium/uranium fuel
Application	Enhance current DOE operation
Rating — Status	Justification completed
Priority	Required for new or ongoing DOE operations

Description of operation and experimental data needed

For the proposed weapons-grade plutonium burner (LWR version), the following critical experiments will be required:

Homogeneous Systems

These experiments will yield data on dry and damp powders to determine critical mass and volume as a function of Pu or U concentration. This information is needed to reduce uncertainties in critical volumes and masses, and to serve as benchmarks for validating calculational methods; this information will be required if mixed oxide fuel is used in LWRs. The variables include (1) the Pu content in mixed oxides at 3 to 6 wt% of PuO_2, (2) the ^{240}Pu content of Pu at 5% of ^{240}Pu, and (3) the H/Pu moderation ratio in the range from 0-3.

Heterogeneous Systems

Data on lattices of fuel rods in water are needed to determine the minimum critical volumes and the effect of heavier isotopes of Pu on criticality. The variables are (1) the fuel-pin diameter, (2) the Pu content in mixed oxides at 3 to 6 wt% of PuO_2, (3) the ^{240}Pu content of Pu at 5 wt% of ^{240}Pu, and (4) the H/Pu moderation ratio in the range from 0-3.

Proposed experimental facility

LACEF

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Experiment 403
Minimum Critical Pu Fraction in Pu/Natural-U Mixture

Contractor Requiring Data		Westinghouse Hanford Company
	Category	Plutonium/uranium fuel
	Application	Enhance current DOE operation
Rating	**Status**	Justification completed
	Priority	Less urgent than 2

Description of operation and experimental data needed
The issue of criticality potential in large, waste storage tanks containing TRU could be resolved in most cases by showing that the plutonium held up with uranium in waste sludges is not more than about 0.6% of the total U + Pu contained in a homogeneous water slurry. The Pu critical fraction would have to be determined as a function of the H/U ratio in the media.

Proposed experimental facility
LACEF

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Criticality Experiments Needed to Support Transportation/Applications: Waste, Storage, and Alarm Systems

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Criticality Experiments Needed to Support Transportation/Applications: Waste, Storage, and Alarm Systems

Experiment 501
Assessment for Materials Used to Transport and Store Discrete Items and Weapons Components

Contractor Requiring Data		All Department of Energy facilities, Pantex, Rocky Flats Plant, Y-12, Savannah River Plant-Westinghouse Company
	Category	Applications
	Application	Enhance current DOE operation
Rating	**Status**	Justification completed
	Priority	Maximum practical attention

Description of operation and experimental data needed

Program Applicability: This program is needed for the current and long-term weapons-component storage mission of the DOE. This program also includes transport and storage of discrete items in well-characterized shipping containers.

Current Calculational Pitfalls and Deficiencies: Criticality safety assessments in this area have an inadequate or nonexistent experimental basis. These assessments have caused over-conservatisms in transport and storage requirements (e.g., the transport index) and the calculations are not validated as prescribed in ANSI/ANS-8.1.

Potential Benefit in Risk Management: This program will enable the DOE to take credit for the neutronics properties of the defined shipping container configurations, which will reduce conservatisms in calculations. This should permit larger numbers of containers to be transported and stored in existing facilities. This program will provide relevant and basic criticality safety data, quantify safety margins more accurately, reduce calculational conservatisms, and establish compliance to ANSI/ANS-8.1.

Description of Program: This program will use currently available U and Pu components and materials commonly used in shipping containers (i.e., iron, stainless-steel, wood, Celotex, lead, firedike, foamglas, expanded borated polyfoam, polyethylene, plexiglas, depleted uranium, and other materials). These will be used in various reflector and moderator configurations so that a wide range of neutron spectra can be obtained under critical conditions. All selected reflector and moderator conditions will be characterized in this program under actual conditions. Neutron fluxes, spectra, and lifetimes within, between, and exterior to the components will be measured. This program specifically applies to pits, weapons components, fuel assemblies, and parts. A specific series of experiments could use the existing enriched uranium hemishells that are delivered to LACEF from RFP in a water-moderated array that contains the interstitial material of choice.

(continued)

Experiment 501 (continued)

Proposed experimental facility	LACEF
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Experimental Program 502
Waste Processing, Transportation, and Storage

Contractor Requiring Data	Hanford, Westinghouse Savannah River Company, Idaho National Engineering Laboratory, Rocky Flats Plant, Oak Ridge National Laboratory, Los Alamos National Laboratory
Category	Applications
Application	Enhance current DOE operation
Rating — **Status**	Justification completed
Priority	Maximum practical attention

Description of operation and experimental data needed

As part of defense-waste cleanup and environmental restoration, fissile materials in large tanks, drums, trenches, and ultimate disposal options for these materials present special criticality problems. Fissionable materials, such as Pu and U, are found in combination with other elements. We propose a series of experiments under this program that would evaluate uranium to plutonium ratios (with both high- and low-enriched uranium) at representative moderator-to-fissile (for example, H and C) material ratios and different levels of diluents.

The diluents could be thermal (Cl, B, Li) or resonance (Fe, Ti) absorbers, low absorption diluents (Zr, Na, Mg, Si, Ca), and simulants for fission products. The diluents could also be in reflectors. Selected combinations of the materials will be used to define ranges of applicability. The measurements could be made using approaches-to-critical or reactivity-replacement experiments. Alternate subcriticality determination measurements should be performed concurrently, especially for approaches-to-critical experiments.

The results from the experiments would provide benchmarks and information to validate computer codes. The validated computer methods should help resolve nuclear criticality issues that currently penalize the processing, transportation, and storage of waste materials. Specific experimental details can be found in Experiments 502a – 502i.

Proposed experimental facility

LACEF

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Experiment 502a
Absorption Properties of Waste Matrices

Contractor Requiring Data	Idaho National Engineering Laboratory
Category	Applications
Application	Enhance current DOE operation, Resolve technical issue
Rating — Status	Justification completed
Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed

Some of the more interesting waste materials are SiO_2, MgO, graphite, cellulose, CaO_2, and NaCl. With the exception of NaCl, these materials are among the more reactive materials that are present in waste. The limiting critical concentration of plutonium or uranium in most of these materials is less than the limiting critical concentration in some of the more traditional and well-known materials, water and polyethylene. However, large differences (greater than 10%) in calculated k_{eff} values are obtained for systems that contain significant quantities of these materials, simply by changing cross-section data sets. Therefore, experimental results are needed to compare with calculational results so that these differences are resolved and realistic biases are established.

Proposed experimental facility

LACEF

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Experiment 502b
In Situ Drum Stacking

Contractor Requiring Data		EG&G Rocky Flats
	Category	Applications
	Application	Enhance current DOE operation
Rating	**Status**	Justification completed
	Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed

Rocky Flats has a large variety of waste drums with a large fissile content distribution and a large variety of matrix material. A lot of the waste is in plastic containers. As a practical matter, these waste drums cannot be individually characterized.

One could stack the drums many layers deep in a large room. This would be accomplished by an *in situ* subcritical experiment that directly measures the approach toward criticality. The objective is not designed to be a scientific experiment, but it is a direct means of getting a simple, unique, and specific configuration of drums that are stacked all the way to the ceiling. The stacking will be done safely and will be shown—by direct reciprocal multiplication measurement—to be well subcritical.

The drums will be left, so stacked, for many years as a means of storage until a processing method has been selected. This approach could prove to be a practical procedure to enhance drum storage capacity.

The successful application of this technique to the characterization of a large array of ill-characterized elements could provide the basis for the development of a procedure to ensure safe storage on a general basis.

Proposed experimental facility

In situ

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Experiment 502c
Validation of WIPP Hydrogen Generation Calculations

Contractor Requiring Data		EG&G Rocky Flats
	Category	Applications
	Application	Enhance current DOE operation, resolve technical and environmental issues
Rating	**Status**	Justification completed
	Priority	Maximum practical attention

Description of operation and experimental data needed

Program applicability: Packaging containerized waste for WIPP.

Calculational deficiency: Hydrogen-gas generation from radiolytic decomposition has been over-conservatively estimated, which artificially limits WIPP shipments and storage.

Cost benefit: Results from this study will allow shipments with higher wattages that approach criticality limits. An increase in storage capacity decreases total shipments.

Program description: Thin uranium sheets or uranium shells interstitially moderated with polyethylene or PVC will be operated at high-power delayed critical or in burst mode. The neutron flux and fission products will produce hydrogen gas. The experiment will be performed in a vessel so that H_2 can be measured. The results will be used to validate the hydrogen-gas generation models for better estimates of hydrogen-gas generation in waste.

Practicability: The fuel and the moderator are available; the pressure vessel and associated H_2 detectors can be fabricated or otherwise obtained.

Proposed experimental facility

LACEF

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Experiment 502d
The In-Tank Precipitation (ITP) Process for ^{235}U

Contractor Requiring Data	Westinghouse Savannah River Company
Category	Applications
Application	Support new DOE program

Rating	**Status**	Justification completed
	Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed

This experiment is needed to support defense-waste processing; in particular, the in-tank precipitation (ITP) process. Currently, there is only one element, titanium, that we can use for criticality control. Because there is more than the minimum critical mass, we use titanium as the absorber that follows the uranium through the process. There are no experiments that use titanium as an absorber to support this application.

At present, this is the only way to process high-level waste in the tanks. The following bullets highlight the experimental details:

- We will use ^{235}U with titanium as a soluble absorber.
- Our preferred $H/^{235}U$ ratios are 125/1, 240/1, 325/1, 385/1, 465/1, and 530/l.
- We prefer low-neutron leakage geometry.
- Our application is for high-pH systems but experiments with low pH may be acceptable if free acid molarity is low.
- We prefer at least 65% enriched uranium.
- The titanium should be natural in isotopic content.

The ITP process is key to long-term storage of wastes from Savannah River waste tanks.

Proposed experimental facility

LACEF

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Experiment 502e
The In-Tank Precipitation Process for $^{235}U + ^{239}Pu$

Contractor Requiring Data		Westinghouse Savannah River Company
	Category	Applications
	Application	Support new DOE program
Rating	**Status**	Justification completed
	Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed

This experiment is needed to support defense-waste processing; in particular, the ITP process. Currently, there is only one element, titanium, that we can use for criticality control. Because there is more than the minimum critical mass, we use titanium as the absorber that follows the uranium through the process. There are no experiments that use titanium as an absorber to support this application.

At present, this is the only way to process high-level waste in the tanks. The following bullets highlight the experimental details:

- We will use $^{235}U + ^{239}Pu$ with titanium as a soluble absorber.
- The maximum useful moderation range $[H/(^{235}U + ^{239}Pu)]$ will be 50/1 to 1000/1, with values around 500 the most important.
- The maximum useful $^{235}U/^{239}Pu$ range will be 1/1 to 10/1, with values around 2/1 to 3/1 the most important.
- Our application is for high-pH systems but experiments with low pH may be acceptable if free acid molarity is low.
- We prefer low-neutron leakage geometry.
- The desired ^{240}Pu and ^{241}Pu content is less than 15% total Pu, or greater than 85% ^{239}Pu.
- The ^{235}U content should be at least 65% enriched.
- The titanium should be natural in isotopic content.

The ITP process is key to long-term storage of wastes from Savannah River waste tanks.

Proposed experimental facility

LACEF

(continued)

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Experiment 502f
The In-Tank Precipitation Process for ^{239}Pu

Contractor Requiring Data	Westinghouse Savannah River Company
Category	Applications
Application	Support new DOE program

Rating	**Status**	Justification completed
	Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed

This experiment is needed to support defense-waste processing; in particular, the ITP process. Currently, there is only one element, titanium, that we can use for criticality control. Because there is more than the minimum critical mass, we use titanium as the absorber that follows the uranium through the process. There are no experiments that use titanium as an absorber to support this application.

At present, this is the only way to process high-level waste in the tanks. The following bullets highlight the experimental details:

- We will use Pu with titanium as a soluble absorber.
- The preferred $H/^{239}Pu$ ratios will be 225/1, 325/1, 385/1, 465/1, and 530/1.
- We prefer low-neutron leakage geometry.
- The ^{240}Pu and ^{241}Pu content we desire is less than 15% total Pu, or greater than 85% ^{239}Pu.
- Our application is for high-pH systems but experiments with low pH may be acceptable if free acid molarity is low.
- The titanium should be natural in isotopic content.

The ITP process is key to long-term storage of wastes from Savannah River waste tanks.

Proposed experimental facility

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Experiment 502g
Determination of Fissionable Material Concentrations in Waste Materials

Contractor Requiring Data	Westinghouse Hanford Company
Category	Applications
Application	Support new DOE program
Rating — Status	Justification completed
Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed

It is important for criticality and accountability purposes to know concentrations of fissionable elements in waste streams or in waste containers. These concentrations may be too low for subcritical measurements. However, total quantities in containers may be substantial and, under some upset conditions, concentrations could increase to become a criticality concern. Knowledge of the total fissionable material content of tanks or drums is important also for material accountability. Neutron detection methods can be used to evaluate fissile concentrations, and therefore total tank inventories. The neutron detection methods have to be calibrated in a facility where calibration standards can be prepared and handled.

Proposed experimental facility

LACEF

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Experiment 502h
Minimum Critical Mass of Fissile-Polyethylene Mixture

Contractor Requiring Data		Savannah River Site, Rocky Flats Plant, Westinghouse Hanford Company, Department of Energy/EM-30 (Waste Isolation Pilot Plant)
	Category	Application
	Application	Storage and transportation of Pu-polyethylene wastes in 55-gal drums; supercompaction of Pu wastes that contain polyethylene
Rating	**Status**	Justification completed
	Priority	Maximum practical attention

Description of operation and experimental data needed

Some plutonium waste in 55-gal drums contains polyethylene [$(CH_2)n$]. Calculations indicate that the minimum critical mass (MCM) for Pu-$(CH_2)n$ mixtures is 360 grams of Pu. This MCM is 30% lower than the MCM for Pu-water mixtures. Because of the higher reactivity of Pu-$(CH_2)n$ mixtures, the criticality safety limits for storage drums and waste carriers are adjusted accordingly.

The higher reactivity is believed to be due to the higher hydrogen density of polyethylene. However, there are no criticality benchmark measurements to confirm the calculation.

Proposed Experiment: Use Pu or HEU foils layered with polyethylene to obtain a criticality measurement benchmark.

Proposed experimental facility LACEF

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Experiment 502i
Criticality Studies That Emphasize Intermediate Energies

Contractor Requiring Data EG&G Rocky Flats Critical Mass Laboratory

Category Applications

Application Enhance current DOE operation

Rating

Status Justification completed

Priority Maximum practical attention

Description of operation and experimental data needed

Many experiments have been done in the past that could be used for some degree of code validation for large, chunky metal systems and for pure and nearly pure solution systems. These experiments were the easiest to do; they were the most needed when nuclear weapons were being manufactured. A plant had pieces of metal and the recovery of the fissile component during subsequent processing lead to many kinds of fissile solutions. The recent decision to stop manufacturing nuclear weapons changes the nature of the processes involved in recovery to a large extent. This decision does not make the potentially dangerous fissile material go away. Instead, the material will be in a much less common form: relatively large quantities of fissile metal will start showing up in recovery plants in processes not encountered years ago.

This waste will be characterized by a high-hydrogen content due to the paper, plastics, rubber, and other organic materials used, but they will also have fissile metal concentrations in potentially critical concentrations.

We propose to devise a set of critical experiments that purposefully approximate the H/X ratio of typical waste streams. We intend to extend this study to include cases where the fissile contaminants are not distributed uniformly.

Proposed experimental facility LACEF

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Experimental Program 503
Validation of Criticality Alarms and Accident Dosimetry

Contractor Requiring Data		Department of Energy Complex
	Category	Applications
	Application	Criticality safety, radiation protection for workers and the public
Rating	**Status**	Justification complete
	Priority	Maximum practical attention

Description of operation and experimental data needed

Criticality accident-alarm systems are used to alert personnel in need of evacuation. Risk reduction requires that the potential for false alarms be minimized. Proper testing and validation requires the ability to provide exposures that simulate accidents for the complete range of potential accident scenarios. Sheba and Godiva can provide this service, particularly when augmented by the HPRR.

Sheba provides a low-energy spectrum characteristic of solution accidents, and Godiva provides the capability for simulating super-prompt critical excursions. In addition, we propose to reactivate the HPRR at LACEF. This well-characterized reactor was specifically developed to evaluate radiation exposures in a mixed (neutron/gamma-ray) environment. It was employed for international intercomparisons of accident dosimetry for over 20 years before its shutdown in 1986.

The data will be used to assure that ANSI and ISO Standards are correct, and that a proper level of protection is provided to workers and the public.

Proposed experimental facility LACEF

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Experimental Program 504
Accident Simulation and Validation of Accident Calculations

Contractor Requiring Data	Department of Energy Complex
Category	Applications
Application	Baseline data

Rating	**Status**	Experimental program
	Priority	Maximum practical attention

Description of operation and experimental data needed

Present safety protection standards and SARs are based on data from accidents, which by their very nature, are not well characterized due to lack of monitoring equipment or, in many instances, accident dosimetry. This program will apply machines such as Godiva, Sheba, and Silene (French) to the validation of accident calculations through the simulation, the development, and the validation of accident models.

ANSI/ANS Standard 8.13 specifies the minimum accident of concern in terms of detectability. However, in the absence of well-characterized experiments to simulate accidents, a highly conservative fission yield must be assumed for the SAR. The results of this assumption are then reflected in overly conservative system design or in reduced inventories of material.

Proposed experimental facility

LACEF

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Experimental Program 505
Evaluation of Measurements for Subcritical Systems

Contractor Requiring Data		Department of Energy Complex
	Category	Applications
	Application	Criticality safety, radiation protection for workers and the public
Rating	**Status**	Justification completed
	Priority	Maximum practical attention

Description of operation and experimental data needed

This program is aimed at developing a meter, or meters, to evaluate the degree of subcriticality in a system or array of fissile material. The need for such a meter has been long recognized, but the difficulties involved are apparent: no such instrument has been developed in the fifty years of work with fissile systems. Techniques that might be employed include (1) source jerk, (2) cross-correlation techniques, (3) Rossi-alpha, (4) pulsed neutron, (5) reciprocal multiplication, and (6) other. Successful development and validation of a technique will contribute substantially to worker and public safety and reduce the degree of conservatism.

Proposed experimental facility

LACEF

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Experiment 506
Safe Fissile Mass Thresholds for an Array of Waste Storage Drums

Contractor Requiring Data		Sandia National Laboratories
	Category	Applications
	Application	Resolve technical issues
Rating	**Status**	Justification completed
	Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed

The stacking of fissile-waste storage drums represents a waste handling, storage, and transportation issue.

We propose to measure neutronic coupling between array components of 55-gal drums. The coupling will be measured for low-fissile-mass drum loading, which will be representative of loadings in waste drums. We hope to establish drum loadings below which infinite arrays are criticality safe.

The purpose of these experiments will be to define loadings below which infinite arrays of touching drums are permissible with no separation between drums required. Conversely, above this threshold limit, we could specify the safe center-to-center spacing for the drum arrays and the upper size limit for the array (3x3x3, 4x4x4, etc.) with a specified fissile-mass loading.

Proposed experimental facility

In situ

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Experimental Program 507
Simulator Development

Contractor Requiring Data		Department of Energy Complex
	Category	Applications
	Application	Support new DOE program, enhance current DOE operation, resolve technical issue, and compliance with DOE orders
Rating	**Status**	Justification completed
	Priority	Required for new or ongoing DOE operation
Description of operation and experimental data needed		Laboratory training, DOE training, and any other courses that deal with nuclear safety and cannot be taught at LACEF need a criticality simulator. The LACEF experience with computer-driven and hardware-assisted simulators is a unique resource for criticality training.
Proposed experimental facility		LACEF
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Experimental Program 508
Development of a Demonstration Experiment

Contractor Requiring Data		Los Alamos National Laboratory
	Category	Applications
	Application	Enhance current DOE operations
Rating	**Status**	Experiment in progress
	Priority	Maximum practical attention

Description of operation and experimental data needed For several years, nuclear criticality safety training classes at LANL have utilized a stack of HEU foils interspersed between lucite plates to demonstrate experimental procedure and the characteristics of multiplying systems. Present day safety and security requirements severely complicate this procedure, increasing the number of instructors who must be involved, and place a strain on the security systems. It is proposed to design and construct an experimental apparatus employing LEU in place of the HEU. This would allow the experiment to be conducted outside of the high-security area.

Proposed experimental facility LACEF

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Criticality Experiments Needed to Resolve Baseline Theoretical Criticality Problems

Table of Contents

Criticality Experiments Needed to Resolve Baseline Theoretical Problems

Experiment 601
Critical Mass Experiments for Actinides

Contractor Requiring Data	Los Alamos National Laboratory, Oak Ridge National Laboratory, Idaho Chemical Processing Plant, Savannah River Site
Category	Baseline theoretical
Application	Processing, transport and storage of special actinide elements
Rating — Status	Justification completed
Priority	Maximum practical attention

Description of operation and experimental data needed

Critical mass estimates have been calculated for some of the actinide elements using reactivity coefficient measurements in fast-metal assemblies. This technique results in large uncertainties in the minimum critical masses. The nuclides ^{236}U, ^{237}Np, ^{241}Pu, ^{242}Pu, ^{241}Am exist in the DOE complex in quantities exceeding critical masses. However, there have been no direct measurements of criticality for any of these special actinides. Therefore, new measurements are necessary for validating mass limits to be used in processing, transport and storage of this material. We can perform some of these measurements to determine the critical mass for these actinides and additional, refined worth measurements for the actinides with higher atomic numbers.

The results of this program would address known inadequacies in the standard ANSI/ANS 8.15, "Nuclear Criticality Control of Special Actinide Elements."

Proposed experimental facility LACEF

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Experiment 602
Neutron Absorber Property of PVC

Contractor Requiring Data		Applicable to most Department of Energy contractors
	Category	Baseline theoretical
	Application	Limited interest for DOE contractors
Rating	**Status**	Experiment completed
	Priority	Less urgent than priority (2)
Description of operation and experimental data needed		PVC plastic Raschig rings are used as a fixed neutron poison in fissile material solutions, similar to the use of Pyrex glass Raschig rings. Experimental criticality data exists for chlorinated-PVC (which is similar to PVC), but a critical benchmark is still needed for PVC tubes or rings in uranium solution to measure and confirm the neutron-absorption property of PVC. The neutron absorber in PVC is chlorine. The advantages of PVC over glass are (1) corrosion resistance in the presence of fluoride ion, and (2) no breakage as with glass.
Proposed experimental facility		LACEF
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Experiment 603
Effect of Poorly Absorbing, Neutron-Scattering Elements on Critical Size

Contractor Requiring Data		Westinghouse Hanford Company
	Category	Baseline theoretical
	Application	Enhance current DOE operation
Rating	**Status**	Experiment in progress
	Priority	Less urgent than priority (2)

Description of operation and experimental data needed

While it can be shown through calculations that the addition of low-atomic-number elements, such as oxygen and aluminum, can decrease the critical mass of reduced-density systems (compared to simply reducing the density of a solution) and decrease the minimum critical solution density and the minimum critical areal density, no experimental data exist to directly determine the magnitude of the effect. This is a concern for other situations in which the critical parameters of fissile bearing wastes are determined.

We propose a criticality experiment to resolve this question.

Proposed experimental facility

LACEF

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Experiment 604
Unusual Fissile Shapes

Contractor Requiring Data		Applicable to most Department of Energy contractors
	Category	Baseline theoretical
	Application	Enhance current DOE operation
Rating	**Status**	Justification completed
	Priority	Less urgent than priority (2)

Description of operation and experimental data needed

Geometry description packages have been provided in various Monte Carlo computer codes to treat unusual shapes that are not the "standard" geometries (spheres, cylinders, and cuboids). These special geometry routines are used frequently in criticality safety analysis. However, with few exceptions, these special geometry routines (e.g., General Geometry in the KENO code and "hole routines" in the MONK code) are always validated against the standard shapes because essentially no experimental data exist for nonstandard geometries. It is proposed that a series of critical experiments be supported that will provide nonstandard geometries (cones, truncated spheres, hemispheres, annular tanks with nonuniform annuli, triangular tanks, etc.) to validate the nonstandard geometry calculations.

Proposed experimental facility

LACEF

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Experimental Program 605
Measurement of Delayed-Neutron Parameters and Time-Dependent, Delayed-Neutron Spectra for ^{235}U, ^{238}U, ^{237}Np, ^{239}Pu, and ^{241}Am

Contractor Requiring Data		Applicable to most Department of Energy contractors
	Category	Baseline theoretical
	Application	Use in modeling criticality accidents, reactor kinetics, and subcriticality measurements
Rating	**Status**	Justification completed
	Priority	Required for new or ongoing DOE operations

Description of operation and experimental data needed
System-applicable, delayed-neutron parameters should be measured for Godiva, Big Ten, Flattop, Sheba, and for several thermal and fast systems on Honeycomb. The parameters include the delayed-neutron yield for each system, the delayed-neutron fraction for each delay group, and the delayed-neutron spectra as a function of time after fission.

Proposed experimental facility
LACEF

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Experiment 605a
Delayed-Neutron Fraction Measurement from ^{237}Np

Contractor Requiring Data		Los Alamos National Laboratory
	Category	Baseline theoretical
	Application	Enhance current DOE operation
Rating	**Status**	Justification completed
	Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed

We propose to measure delayed-neutron flux spectra from ^{237}Np. A ^{235}U target will be used as the reference. A time domain of 0.5 sec to 5 sec after fission will be used. We need very small self-multiplication; a 1-gm sample will suffice. NE213 and Cutler-Shalev detectors will be used to measure the neutron spectrum over the energy range 5 keV to 5 MeV.

The fissions will be produced using Godiva-IV, and the target samples will be transferred using the existing pneumatic system that connects the existing counting system in Kiva III.

Proposed experimental facility

LACEF

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Experiment 605b
Measurement of Time-Dependent, Delayed-Neutron Spectra

Contractor Requiring Data	Applicable to most Department of Energy contractors
Category	Baseline theoretical
Application	Resolve technical issue
Rating — Status	Justification completed
Priority	Less urgent than priority (2)
Description of operation and experimental data needed	Some discrepancies need to be reconciled to the various measurements and syntheses of equilibrium delayed-neutron spectra; it may be necessary to consider the time variation of delayed-neutron spectra in fast-reactor calculations. These data would be of interest in the nuclear power industry, in criticality safety determinations for the production and handling of nuclear materials, and in the investigation of neutron-rich nuclei in the study of nuclear structure.
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Experiment 606
Establishing the Validity of Neutron-Scattering Kernels

Contractor Requiring Data		Applicable to most Department of Energy contractors
	Category	Baseline theoretical
	Application	Fissile systems controlled by separation with moderating materials
Rating	**Status**	Justification completed
	Priority	Maximum practical attention

Description of operation and experimental data needed

Slowing-down measurements made by the National Institute of Science and Technology indicate discrepancies of up to 7% in thermal fission activities.

Assessment of discrepancies between experiments and calculations of neutron-scattering kernels for moderating materials, both fissile and nonfissile, has indicated a need for basic physics measurements with various compounds such as mixtures of the elements H, O, and C in water, polyethylene, Plexiglas, and other compounds.

Proposed experimental facility

NIST, LACEF

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Experiment 607
Extending the Standard ANSI/ANS 8.7 to Moderated Arrays

Contractor Requiring Data		Applicable to most Department of Energy contractors, Rocky Flats Plant, Los Alamos National Laboratory, Savannah River Site, Y-12, Oak Ridge National Laboratory, Lawrence Livermore National Laboratory
	Category	Baseline theoretical
	Application	Enhance current DOE operation
Rating	**Status**	Justification completed
	Priority	Maximum practical attention

Description of operation and experimental data needed

This ANSI/ANS standard 8.7, "Guide for Nuclear Criticality Safety in the Storage of Fissile Materials," currently applies to low-moderated and unmoderated fissile material. A criticality experimental program will extend this standard to moderated arrays as well. This standard has a high level of demonstrated usefulness in safety analyses for fissile material storage and transportation. The experiments would vary array unit moderation, array size, array spacing, and room return on a parametric basis.

Proposed experimental facility

LACEF

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Experiment 608
Fission Rate Spectral Index Measurements in Three Assemblies

Contractor Requiring Data	Potential use by Department of Energy Cross-Section Working Evaluation Group
Category	Baseline theoretical
Application	Resolve technical issue

Rating	**Status**	Justification completed
	Priority	Maximum practical attention

Description of operation and experimental data needed

In 1978, fission rates for the isotopes ^{235}U, ^{238}U, ^{237}Np, and ^{239}Pu were measured in the neutron spectra at the center of Flattop, with a 93% ^{235}U core, and Big Ten, a 10% ^{235}U assembly machine. However, these data are suspect, since the detector developed a leak during the measurements.

The purpose of this experiment is to repeat the 1978 measurements and provide more reliable data for use to validate differential fission cross sections in different spectral systems. In addition, other measurements could be made using actinide samples, particularly the threshold fission actinides ^{238}Pu, ^{242}Pu, etc.

Proposed experimental facility LACEF

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Experiment 609
Validation of Calculational Methodology in the Intermediate Energy Range

	Contractor Requiring Data	Los Alamos National Laboratory, Oak Ridge National Laboratory, Rocky Flats Plant, Savannah River Site, Lawrence Livermore National Laboratory, Enriched facilities, etc.
	Category	Baseline theoretical
	Application	Initial request
Rating	**Status**	Justification completed Fissile material in facilities under remediation and decommissioning are subject to low-moderation and generate intermediate energy spectra.
	Priority	Maximum practical attention

Description of operation and experimental data needed

Criticality calculations for systems involving relatively thin fissile regions (1- to 3-mm thick separated by 1 to 3 cm of hydrogenous material) would depend on the accuracy of cross sections pertinent to those systems. A search of the literature fails to find any critical experiments for which a large fraction of the fissions occur between neutron energies of 1 eV and 100 KeV. Many experiments have been done for thermal systems (fissile solutions) for which nearly all fissions occur at energies below 1 eV.

At the other extreme, many experiments have been done for "fast" systems (fissile solids) for which nearly all fissions occur at energies above 100 KeV and up to 2 MeV.

This situation leaves a very large range of systems which have <u>never</u> been tested experimentally. For any thermal systems, neutrons must decelerate from fast to thermal. The neutrons exist and interact at many energies between fast and thermal. Furthermore, this region is often characterized by the "resonance region," which exhibits wide fluctuations in cross section.

One does not know if good agreement between theory and experiment for a thermal system is the result of:

1. error canceling in the codes that handle neutron deceleration through these energies; or
2. a real bias in the code that happens to be in opposition to the errors in the code's handling of neutron deceleration.

(continued)

Experiment 610 (continued)

Description of operation and experimental data needed *(continued)*

One does not know if an observed bias between theory and experiment for a thermal system is the result of:

1. errors in the code's handling of neutron deceleration through these energies, errors which do not cancel; or
2. a real bias in the code that is added to, subtracted from, or unaffected by the code's handling of neutron deceleration.

These cross sections are defined in the existing cross section data sets, but little data exist to verify that these cross sections are correctly represented.

We have designed an experiment to provide such a test.

Proposed experimental facility

LACEF

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Criticality Experiments Needed to Support Criticality Physics Operations

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Criticality Experiments Needed to Support Criticality Physics Operations

Experimental Program 701
Investigation and Development of Subcritical Measurements

Contractor Requiring Data	Los Alamos National Laboratory, Oak Ridge National Laboratory, Rocky Flats Plant, Lawrence Livermore National Laboratory, Sandia National Laboratories
Category	Criticality physics
Application	Handling and storage of significant quantities of fissile material, (e.g., Complex 21)
Rating — **Status**	Justification completed
Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed

Measurement of the delayed critical point is relatively easy and commonly done. The measurement of $k_{eff} < 1.0$ is more difficult with the situation getting worse as the measurement is attempted further away from critical.

The availability of a simple reliable measurement of subcritical reactivity would be valuable for many applications:

- Periodic checks on the subcriticality of storage areas — checks on the loss of hydrogen or the leaching of poison from storage vault concrete.
- Measurement of the reactivity of reactor core subassemblies before they are inserted into the reactor core.
- Measurement of the reactivity of SNM or SNM waste before these materials are inserted into highly reflecting and moderating well counters and assay chambers.

Developing procedures and investigating the accuracy and ranges of validity for a number of techniques used in subcritical reactivity measurements would provide valuable results for much of the DOE community that handles or stores significant quantities of SNM.

Techniques that would be employed include (a) source jerk, (b) cross-correlation techniques, e.g., ^{252}Cf noise analysis, (c) Rossi-alpha, (d) pulsed neutron, and (e) reciprocal multiplication.

(continued)

Proposed experimental facility LACEF

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Experiment 702
Spent Fuel Safety Experiments (SFSX)

Contractor Requiring Data	Sandia National Laboratories
Category	Applicable experiment categories
Application	Applications are throughout the DOE complex for the storage, transportation, disposal of spent nuclear fuel from DOE reactors as well as from commercial reactors in support of the Civilian Radioactive Waste Management Program. Data from these experiments could also be used by commercial reactors and the NRC to evaluate on-site storage of spent fuel.
Rating **Status**	Justification completed
Priority	Maximum practical attention

Description of operation and experimental data needed

The following information is required to validate burn-up credit:

1. Fuel Rod Consolidation.

   The MRS may provide the capability to disassemble fuel assemblies and consolidate the fuel rods in storage canisters. Experimental data will benefit the safety and economics of this operation.

2. Spent Fuel Burnup Versus Reactivity.

   DOE contractors and NRC licensees are interested in obtaining criticality data for spent LWR fuel to confirm calculations. Operational and storage restrictions can be significantly reduced if credit could be taken for burnup. The calculations must account for: (1) ^{235}U depletion and fission product formation, which decrease reactivity; and (2) the formation of plutonium, which increases reactivity.

3. Reactivity Worth of Spent Fuel.

   The reactivity worth of spent fuel samples that are from a fully characterized spent fuel assembly would have to be experimentally verified. This verification would include chemical assay data.

4. Approach to Critical

   An approach to critical would have to be performed for (1) an array of fresh fuel rods (the lattice should be composed of differing enrichment rods, water rods and Gd-bearing rods to simulate BWR); (2) central rods replaced with spent fuel that represent average assembly conditions; and (3) central rods replaced with spent fuel rods that represent the burnup that is typical of the tips of fuel rods and is a consequence of the axial burnup distribution in PWRs.

(continued)

Proposed experimental facility SNL

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Experimental Program 703
Differential Parameter Measurements

Contractor Requiring Data		Rocky Flats Critical Mass Laboratory, Department of Energy Complex
	Category	Criticality physics
	Application	Enhance current DOE operation
Rating	**Status**	Justification completed
	Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed

At the present time, all code validation is done by comparing only the one "integral" parameter, namely k_{eff}, between experiment and theoretical calculation. This validation is done only at delayed criticality, or $k_{eff} = 1.00$. However, computer codes give much more information than just this single, integral parameter. They give neutron fluxes, or currents in various regions, and a wealth of other data. These might be called "differential data" because their absolute value would depend on the instantaneous power level of the critical configuration. Still, the relative magnitude of some differential parameter at one location relative to another location would be independent of power level. This magnitude would be another independent test of the code's ability to estimate the real conditions.

We propose to set up an experimental program to measure these differential parameters in addition to the integral parameter, k_{eff}. Such a study would be designed to assure that an observed perfect agreement between theory and experiment (zero bias) in a particular validation was not just due to the accidental cancellation of opposing errors within the code. Experiments within this program would be very simple geometrical systems; and the material compositions would be almost irrelevant. However, the boundaries between one material and another should be clearly defined at least in two widely separated locations.

This will promote more effective utilization of all data available such as in Experiments 208 and 608.

Proposed experimental facility

LACEF

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Experimental Program 704
Homogeneity versus Heterogeneity

Contractor Requiring Data	Department of Energy Complex
Category	Applicable experimental categories
Application	Enhance current DOE operation
Rating — Status	Justification completed
Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed

Several experiments should be performed to illustrate the difficulties in making simplifying assumptions, which are of general interest for developing second-order corrections to analytical techniques.

For example how small must a cell of one material surrounded by another material be before one can consider that a truly heterogeneous mixture is neutronically homogeneous?

One example of this problem would be Raschig-ring-filled tanks containing fissile solution. Another example would be a uniform suspension of foreign material in an otherwise homogeneous fissile solution.

The practical issue is this: are we wasting too much time calculating and modeling heterogeneous systems when not much accuracy would be lost in assuming that the entire system is homogeneous? Or, conversely, do we too easily make the assumption of homogeneity when we should be modeling a heterogeneous system?

Although these questions are usually answered by calculations, it would be desirable to validate several of these calculations by a few selected experiments.

Proposed experimental facility

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Experiment 705
How to Measure Hydrogen

Contractor Requiring Data		Rocky Flats Critical Mass Laboratory
	Category	Applicable experimental categories
	Application	Enhance current DOE operation; all hydrogenous materials
Rating	**Status**	Justification complete
	Priority	Less urgent than priority (2)

Description of operation and experimental data needed

This proposal would be a nonfissile experiment. It is designed to devise a new analytical capability to improve the way laboratories measure the properties of fissile solutions.

In practice, an analytical laboratory can measure the fissile metal content of a solution to a little better than ± 1%. The same laboratory cannot measure the hydrogen content of a complex solution—such as a nitrate solution of a metal salt—to much better than ± 5%. The impact upon the calculated k_{eff}, however, proves to be 3-times more sensitive to uncertainties in H concentration than to the measurement uncertainty in U or Pu concentration. Thus, a the uncertainty in H concentration contributes about 15-times more to errors in k_{eff} than does the uncertainty in the fissile content.

We propose to develop a laboratory method to measure the hydrogen content of a true-but-complex solution to better than ± 0.3%.

Proposed experimental facility

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Experiment 706
"Dry Water"

Contractor Requiring Data		Department of Energy Complex
	Category	Applicable experimental categories
	Application	Enhance current DOE operation
Rating	**Status**	Justification completed
	Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed

We propose to design an experiment to measure the critical parameters of a fissile "solution" where hydrogen content is accurately measured. This would be accomplished by blending a "dry" fissile solution composed of powdered, or finely ground, plastic granules and the powdered oxide of a fissile metal. This mixture should have the same H/X ratio as an aqueous solution might have, but it would be better known because the laboratory analysis of both the metal oxide and the plastic would be accurate in both cases. The granular size of the powders would have to be small enough so that the fabricated "solution" would neutronically resemble a homogeneous situation in spite of the obvious fact that any mixture of plastic and oxide would be truly heterogeneous.

Proposed experimental facility

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Experiment 707
Anomalous Critical Experimental Results

Contractor Requiring Data	Department of Energy Complex
Category	HEU, Pu, Criticality Physics
Application	Resolve technical issue
Rating — **Status**	Justification completed
Priority	Required for new or ongoing DOE operation
Description of operation and experimental data needed	When critical experimental results are compared with the results of Monte Carlo calculations, the calculated values of k_{eff} are typically within a few percent of 1.0. There are, however, several critical experiments for which the calculated values of k_{eff} are near 0.90. These calculated k_{eff} factors are quite far from the expected value of 1.0, and are nonconservative. These experiments included an array of high-enriched uranyl nitrate slabs and cylinders, a Pu ball reflected by Be, and others. Several of these experiments should be repeated in order to confirm if the experimental results are incorrect or if the codes are wrong.
Proposed experimental facility	LACEF
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Archived Experiments

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Archived Experiments

Experiment 801
Fuel-Processing Restoration Project

Contractor Requiring Data		Westinghouse Idaho Nuclear Company
	Category	Highly enriched uranium
	Application	Support new DOE program
Rating	**Status**	Experiment in progress
	Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed
The Fuel-Processing Restoration Project is in the final design stage. The criticality experiments needed to support design and operation have been identified and are in progress at the Los Alamos Critical Experiments Facility.

Proposed experimental facility
LACEF

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Experiment 802
Fluorinel and Storage (FAST) Facility

Contractor Requiring Data		Westinghouse Idaho Nuclear Company
	Category	Highly enriched uranium
	Application	Support new DOE program
Rating	**Status**	Experiment complete
	Priority	Required for new or ongoing DOE operation
Description of operation and experimental data needed		The Fluorinel and Storage (FAST) Facility is now in operation. A series of criticality experiments to support this facility were completed in 1986. One additional experiment remains to be completed. This is an experiment to measure the effect of a cadmium/boron poison mixture on the critical size of a cylinder of U(93) uranyl nitrate (see Experiment 103).
Proposed experimental facility		LACEF
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Experiment 803
Mixtures of Soluble Boron and Cadmium

Contractor Requiring Data		Westinghouse Idaho Nuclear Company
	Category	Highly enriched uranium
	Application	Enhance current DOE operation
Rating	**Status**	Justification completed
	Priority	Maximum practical attention

Description of operation and experimental data needed

The use of two soluble neutron poisons (boron plus cadmium) in a fissile solution results in two benefits. First, one poison is a backup, chemically, to the other. Second, advantage can be taken of the broader range of neutron-absorption cross sections in the resonance region. Because their high-neutron-absorption cross sections occur at different neutron energies (even though they overlap), boron and cadmium together may be more effective in some operations than either one alone. The actual margin of safety with two poisons, however, is not known—the synergistic effect has not been measured. A benchmark critical experiment is needed to verify this concept. The first application would be the Fluorinel and Storage (FAST) Facility (see Experiment 102). The Westinghouse Idaho Nuclear Company is anxious that this experiment be performed to provide support for their fluorinel-dissolution process operations.

Proposed experimental facility

LACEF

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Experiment 804
Glycol-Water/Boron Mixture

Contractor Requiring Data		Y-12 Plant (Martin Marietta Energy Systems)
	Category	Highly enriched uranium
	Application	Enhance current DOE operation
Rating	**Status**	Justification completed
	Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed

Personnel at the Y-12 Plant have identified the need for this experiment for highly enriched ^{235}U systems. The glycol/water mixture is used as a coolant in machining operations. The boron concentration in glycol/water solutions can be made several times higher than in water alone before boron precipitation occurs. A criticality measurement of a simple water/boron system could result in more economical operations.

Proposed experimental facility

LACEF

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Experiment 805
Carbon-Reflected U(93) Plant (MMES)

Contractor Requiring Data		Y-12 Plant (Martin Marietta Energy Systems)
	Category	Highly enriched uranium
	Application	Enhance current DOE operation
Rating	**Status**	Justification completed
	Priority	Required for new or ongoing DOE operation
Description of operation and experimental data needed		More refined criticality data on carbon-reflected 93%-enriched uranium metal could result in production improvements at the Y-12 Plant.
Proposed experimental facility		LACEF
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Experiment 806
U(93) Metal Reflected by Refractory Materials

Contractor Requiring Data		Y-12 Plant (Martin Marietta Energy Systems)
	Category	Highly enriched uranium
	Application	Enhance current DOE operation
Rating	**Status**	Justification completed
	Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed

No experimental benchmarks are available for common and specialized refractory materials. It is expected that benefits to the Y-12 Plant and other operations will justify the experiment.

Proposed experimental facility

LACEF

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Experiment 807
Multi Megawatt Reactor Program (canceled)

Contractor Requiring Data		Idaho National Engineering Laboratory
	Category	Highly enriched uranium
	Application	Support new DOE program
Rating	**Status**	Justification completed
	Priority	Required for new or ongoing DOE operation
Description of operation and experimental data needed		Planning is in the preliminary stages for this reactor program. The RFPs will be evaluated in the fall of 1987. The need for criticality experiments to support this project should be assessed about January 1988.
Proposed experimental facility		LACEF
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Experiment 808
Compact Nuclear Power Source (CNPS)

Contractor Requiring Data	Not yet identified
Category	Low enriched U
Application	Support new DOE program
Rating — **Status**	Experiment complete
Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed

The CNPS will comprise about 492 fuel pins in a graphite matrix, arranged in a 4.775-cm-square lattice. The fuel is 19.9%-enriched ^{235}U in a uranium-carbon-oxygen mixture. The fuel pins are 1.245 cm in diameter, and the fuel is 10.65 g/cm^3. Consideration is being given to military use (United States) and civilian use (Canada) for the CNPS.

Two phases of criticality experiments to support this program have been identified as follows:

Phase 1: Experiments to support reactor technology.

These experiments are in progress at the LACAF.

Phase 2: Experiments to support criticality safety applications.

Experiments will be needed to support nuclear criticality safety in the areas of fuel fabrication, storage, transport, and reprocessing.

Proposed experimental facility

LACEF

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Experiment 809
Refurbishment or Replacement for N-Reactor

Contractor Requiring Data		Westinghouse Hanford Company
	Category	Low-enriched uranium
	Application	Support new DOE program
Rating	**Status**	Justification completed
	Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed

If the N-Reactor is replaced and a different fuel type is used in the new reactor, new criticality experiments will be needed to support this reactor. Requirements will not be clarified, however, until 1988-1992. Several options currently exist for this project: use of a WPPS nuclear fuel reactor, currently under construction, or construct a new production reactor.

If the N-Reactor were placed in a tritium production mode, different fuel elements will be used in the reactor. The fuel could use some higher enrichment and be made out of a special alloy. Critical mass measurements or *in situ* measurements would be needed to better define operational critical mass parameters. The need for such measurements would be identified in FY 1988 - 1989.

Proposed experimental facility

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Experiment 810
Special Isotope Separation (SIS) (canceled)

Contractor Requiring Data		Westinghouse Idaho Nuclear Company
	Category	Plutonium
	Application	Support new DOE program
Rating	**Status**	Justification completed
	Priority	Required for new or ongoing DOE operation

Description of operation and experimental data needed

The Special Isotope Separation (SIS) project will separate ^{239}Pu from plutonium mixtures high in ^{240}Pu. Experiments needed to support SIS have not been completely defined. Expected needs are given below:

$PuCl_3$ Solutions: The SIS facility employs an aqueous process involving $PuCl_3$ solution for the recovery of plutonium from the waste streams of various pyrochemical processes. Criticality data on $PuCl_3$ solution system is currently not available; hence, critical experiments on $PuCl_3$ solution are needed before (1) the credit presented by chlorine as a neutron poison can be properly accounted for in the design, and (2) the calculational methods used in the design can be properly validated. Such criticality data are also beneficial to other plutonium facilities using hydrochloric acid as a means of plutonium recovery.

Plutonium Hydride: The SIS facility employs a hydriding/dehydriding process for the recovery of plutonium from the AVLIS system. No criticality data on plutonium-hydride is currently available, and designing the process or verifying the design parameters based on criticality data of other forms of plutonium may or may not be conservative. Therefore, a need for critical experiments with plutonium-hydride is identified for the design, as well as for the validation of the calculational method.

Salt-Reflected/Moderated System: The pyrochemical processes employed by the SIS facility involves plutonium metal in a salt-reflected/moderated system.

Proposed experimental facility

LACEF

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Experiment 811
Neutron Absorber Property of Pyrex Cylinder Walls

Contractor Requiring Data	Applicable to most Department of Energy contractors
Category	Criticality Physics
Application	Support new DOE program

Rating

Status	Justification completed
Priority	Less urgent than priority (2)

Description of operation and experimental data needed

The boron in Pyrex glass cylinder walls reduces the neutron interaction between cylinders. This suggests that Pyrex glass cylinders in a storage array could be closer together than present practice. Before storage operations can take advantage of this reduced spacing, however, a criticality experiment is needed to provide verification data.

Note: The poisoning effect of Pyrex cylinder walls could be studied during the neutron interaction experiments (see Experiment 601).

Proposed experimental facility

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Appendix A
Glossary of Nuclear Criticality Terms

albedo, neutron: The probability, under specified conditions, that a neutron entering into a region through a surface will return through that surface.

absorbed dose: The energy imparted to matter by directly or indirectly ionizing radiation per unit mass of irradiated material at the point of interest; unit of absorbed dose has been the rad and now, in the International System of Units (SI) is the gray (Gy), 100 rad = 1 Gy.[2,3] See *rad, gray.*

absorption, neutron: A neutron-induced reaction, including fission, in which the neutron disappears as a free particle.[1] The absorption cross section is designated σ_a. See *capture, neutron; cross section, neutron.*

alarm system, criticality accident: A system capable of sounding an audible alarm after detecting neutron or gamma radiation from a criticality accident. See *criticality accident.*

alpha particle: A helium-4 nucleus emitted during a nuclear transformation.[1]

beta particle: An electron of either positive or negative charge that has been emitted in a nuclear transformation.[1]

buckling: For our purposes, algebraic expressions that relate critical dimensions of various simple shapes (sphere, cylinder, or cuboid) of cores of the same composition and similar reflectors. For example, the known radius of a critical sphere may be used to obtain the radius and length of a corresponding critical cylinder. For a specific definition of buckling, see Ref. 4, pp 7 and 8. See *core, reflector.*

burst, prompt: Usually refers to the pulse of energy from fissions produced by a prompt burst reactor. See *prompt burst reactor, spike (in a prompt power excursion).*

capture, neutron: Neutron absorption not leading to fission or other neutron production. The capture cross section is designated σ_c. See *absorption, neutron; cross section, neutron.*

cent: A unit of reactivity equal to one-hundredth of the increment between delayed criticality and prompt criticality (a dollar).[1] See *dollar, reactivity*

chain reaction, fission: A sequence of nuclear fission reactions in which fissions are induced by neutrons emerging from preceding fissions. Depending on whether the number of fissions directly induced by neutrons from one fission is on the average less than, equal to, or greater than unity, the chain reaction is, respectively convergent (subcritical), self-sustaining (critical), or divergent (supercritical).[1]

core: That part of a fissile system containing most or all of the fissile material, as distinguished from an external reflector. See *fissile system, reflector.*

critical infinite cylinder: For specified fissile medium and surrounding reflector, the infinitely long cylinder with a diameter that would be critical.

critical infinite slab: For specified fissile medium and reflector on each surface, the slab of infinite lateral dimensions with a thickness that would be critical.

criticality accident: The release of energy as a result of accidentally producing a self-sustaining or divergent fission chain reaction.[1]

criticality safety Standards: These Standards describe criticality control practices for which there is industry-wide consensus. Consensus is established through procedures of the American National Standards Institute. Chapter 4 of Ref. 4 lists and discusses existing and proposed criticality safety Standards, and explains capitalization of the term.

cross section (σ), neutron: The proportionality factor that relates the rate of a specified reaction (such as capture or fission) to the product of the number of neutrons per second impinging normally onto a unit area of a thin target and the number of target nuclei per unit area. It may be considered a small area assigned to each target nucleus, usually expressed in barns, i.e., 10^{-24} cm^2 . See *absorption, neutron; capture, neutron; fission, nuclear.*

decay, radioactive: A spontaneous nuclear transformation in which particles or gamma radiation is emitted, in which x-radiation is emitted following orbital electron capture, or in which the nucleus undergoes spontaneous fission.[1] See *fission, nuclear; gamma radiation.*

delayed criticality: State of a fissile system such that $k_{eff} = 1$, the steady-state condition. See *multiplication factor.*

delayed neutrons: Neutrons from nuclei produced by beta decay following fission. They follow fission by intervals of seconds to minutes. See *prompt neutrons.*

dollar: A unit of reactivity equal to the increment between delayed criticality and prompt criticality for a fixed chain-reacting system. See *reactivity.*

dose equivalent: The absorbed dose multiplied by the quality factor and other less significant modifying factors, so that doses from different radiations (alpha, beta, gamma, slow neutron, fast neutron) can be summed to provide an effective total dose at the point of interest.[2] The conventional unit of dose equivalent has been the rem, and now in the International System of Units (SI) is the sievert (Sv), 100 rem = 1 Sv.[5] See *rem, sievert.*

dose rate: Absorbed dose delivered per unit time.[2] See *absorbed dose.*

excursion, nuclear: An episode during which the fission rate of a supercritical system increases, peaks, and then decreases to a low value.

excursion, prompt-power: A nuclear excursion as the result of a prompt-critical configuration of fissile material. In general, a sharp power spike followed by a plateau that may be interrupted by smaller spikes. See *excursion, nuclear; spike (in a prompt power excursion).*

excursion period (T): The reciprocal coefficient of t, where fission power in a nuclear excursion increases as $e^{t/T}$ before a quenching mechanism becomes effective. See *excursion, nuclear; quenching mechanism.*

exponential column: A subcritical block or cylinder of fissile-bearing material with an independent neutron source at one end. Under appropriate conditions, the response of a neutron detector decreases exponentially with distance from the source. From the logarithmic rate of this decrease and lateral dimensions of the column, critical dimensions of an unreflected assembly of the material may be deduced.

exposure: A measure of the ionization produced in air by x-rays or gamma radiation; the sum of electric charges on all ions of one sign in a small volume of air when all electrons liberated by photons are completely stopped, per unit mass of the air. Note that exposure refers to the environment, not absorbing material. The unit of exposure is the roentgen.[2] See *gamma radiation, roentgen.* Alternatively, exposure is the incidence of radiation on living or inanimate material.[1]

favorable geometry: Geometric constraint of fissile material in which subcriticality is maintained under anticipated conditions. Examples are limited diameter of pipes intended to contain fissile solution, or limited volumes of solution containers.

fissile nuclide: A nuclide capable of fission by thermal neutrons, provided the effective neutron production cross section, $\overline{\nu\sigma_f}$ exceeds the effective absorption cross section, $\overline{\sigma_a}$. The common fissile nuclides are ^{235}U, ^{239}Pu, and ^{233}U.[1] See *absorption, neutron; fission, nuclear.*

fissile system: A system containing ^{235}U, ^{239}Pu, or ^{233}U (or certain other transuranic) nuclides and capable of significant neutron multiplication. See *fissile nuclide; multiplication, subcritical.*

fission, nuclear: Disintegration of a nucleus (usually Th, U, Pu, or heavier) into two (rarely more) masses of similar order of magnitude, accompanied by a large release of energy and the emission of neutrons.[1] Although some fissions take place spontaneously, neutron-induced fissions are of major interest in criticality safety. The fission cross section is designated σ_f, and ν is the number of neutrons emitted per fission. See *cross section, neutron.*

fission products: Nuclides produced by fission or by the subsequent radioactive decay of nuclides formed in this manner.[1] See *fission, nuclear; nuclide.*

fission yield, excursion: The total number of fissions in a nuclear excursion. See *excursion, nuclear.*

fissionable nuclide: A nuclide capable of fission by neutrons of some energy. Fissionable nuclides include ^{238}U, ^{240}Pu, and others with neutron-energy fission thresholds, in addition to those that are fissile. See *fissile nuclide.*

gamma radiation: Short-wavelength electromagnetic radiation emitted in the process of nuclear transition or particle annihilation.[1]

gray (Gy): A unit of absorbed dose; 1 Gy = 1 J/kg = 100 rads. Adopted in 1976 by the International Conference on Weights and Measures to replace the rad.[5] See *rad.*

hazard: A potential danger. "Potentially hazardous" is redundant. Note that a hazardous facility is not necessarily a high-risk facility. See *risk.*.

H/X: Conventionally, the atomic ratio of hydrogen to ^{235}U, ^{239}Pu, or ^{233}U in a solution or hydrogenous mixture. Where there is more than one fissile species, the ratios must be specified separately.

inhour: A unit of reactivity that, when added to a delayed-critical system, would produce a period of one hour; now seldom used.[1] See *reactivity.*

Ionizing radiation: Any radiation consisting of directly or indirectly ionizing particles, photons, or a mixture or both. X-rays and the radiations emitted in radioactive decay are examples.[1] See *decay, radioactive.*

Irradiation: Exposure to ionizing radiation.[1] See *exposure (alternative definition).*

Isotopic code: Combined final digits of atomic number and atomic weight, such that ^{235}U, and ^{239}Pu are represented "25," "49," and "23"; ^{240}Pu, however, is called "410"; these appear in some documents but now are seldom used.

linear energy transfer (LET): The average energy lost by an ionizing radiation per unit distance of its travel in a medium. A high LET is generally associated with protons, alpha particles, and neutrons, whereas a low LET is associated with x-rays, electrons, and gamma rays.[2] See *ionizing radiation.*

monitor, radiation: A detector to measure the level of ionizing radiation. A purpose may be to give information about dose or dose rate.[1] See *ionizing radiation.*

multiplication, subcritical: In a subcritical fissile system containing a neutron source, the equilibrium ratio of the total number of neutrons resulting from fission and the source to the total number of neutrons from the source alone.[1]

multiplication factor (k_{eff}): For a chain-reacting system, the mean number of fission neutrons produced by a neutron during its life within the system. It follows that $k_{eff} = 1$, if the system is critical; $k_{eff} < 1$, if the system is subcritical; $k_{eff} > 1$, if the system is supercritical.

neutron: An elementary particle having no electric charge, a rest mass of 1.67495×10^{-24} g, and a mean life of about 10 min.[1]

neutron poison: A nonfissionable neutron absorber, generally used for criticality control. See *absorption neutron: capture, neutron.*

neutrons, epithermal: Neutrons of kinetic energy greater than that of thermal agitation, often restricted to energies comparable with those of chemical bonds.[1]

neutrons, fast: Neutrons of kinetic energy greater than some specified value, often chosen to be 0.1 MeV (million electron volts).[1]

neutrons, thermal: Neutrons in thermal equilibrium with the medium in which they exist.[1] At room temperature, the mean energy of thermal neutrons is about 0.025 eV (electron volt).

nonfavorable geometry: See *favorable geometry.*

nuclide: A species of atom characterized by its mass number, atomic number, and a possible, elevated, and prolonged nuclear energy state.[1]

oralloy (Oy): Introduced in early Los Alamos documents to mean enriched uranium (<u>O</u>ak <u>R</u>idge <u>alloy</u>); now uncommon except to signify highly enriched uranium. See *tuballoy.*

personnel monitor (radiation): A device for measuring a person's exposure to radiation. Information on the dose equivalent of ionizing radiation to biological tissue is derived from exposures recorded by film badges, ionization chambers, and thermoluminescent devices; from whole-body counting and analysis of biological specimens; and from area monitoring and special surveys.[2]

photon: A quantum of electromagnetic radiation.[1]

prompt burst reactor: A device for producing nondestructive super-prompt-critical nuclear excursions. See *burst, prompt; excursion, nuclear.*

prompt criticality: State of a fissile system such that the prompt-neutron contribution to k_{eff} equals unity. See *multiplication factor.*

prompt neutrons: Neutrons emitted immediately during the fission process. See *delayed neutrons.*

quality factor (QF): The linear energy-transfer-dependent factor by which absorbed doses are multiplied to obtain, for radiation-protection purposes, a quantity that expresses on a common scale the biological effectiveness of the absorbed dose derived from various radiation sources.[2] Approximately the ratio of dose equivalent and absorbed dose. See *absorbed dose, dose equivalent, linear energy transfer.*

quenching mechanism: physical process other than mechanical damage that limits an excursion spike. Examples are thermal expansion, or microbubble formation in a solution. See *spike* (in a prompt power excursion).

rad: A unit of absorbed dose; 1 rad = 10^{-2} J/kg of the medium. In 1976, the International Conference on Weights and Measures adopted the gray (1 Gy = 1 J/kg) as the preferred unit of absorbed dose,[5] but this unit has not appeared in the criticality-accident literature, which was essentially complete before that date. See *absorbed dose, gray, and discussion under personnel monitor.*

radiation: In context of criticality safety, alpha particles, beta particles, neutrons, gamma rays, and combinations thereof. See *alpha particle, beta particle, neutron, x-ray.*

reactivity: A parameter of a fissile system that is proportional to $1 - 1/k_{eff}$. Thus, it is zero if the system is critical, positive if the system is supercritical, negative if the system is subcritical. See *dollar, cent, and inhour, various units of reactivity; multiplication factor.*

reflector: Material outside the core of a fissile system capable of scattering back to the core some neutrons that would otherwise escape. See *core, fissile system.*

reflector savings: The absolute difference between a dimension of the reflected core of a critical system and the corresponding dimension of a similar core that would be critical if no reflector were present.[1] See *core, fissile system, reflector.*

relative biological effectiveness (RBE): A factor used to compare the biological effectiveness of absorbed radiation doses (i.e., rads or grays) because of different types of ionizing radiation; more specifically, it is the experimentally determined ratio of an absorbed dose of a radiation in question to the absorbed dose of a reference radiation required to produce an identical biological effect in a particular experimental organism or tissue.[3] This term should be used only in radiobiology, not instead of the term "quality factor" in radiation protection. See *quality factor.*

rem: A unit of dose equivalent (Roentgen Equivalent, Man), replaced by the sievert, which was adopted in 1980 by the International Conference on Weights and Measures.[5] This unit, however, has not appeared in the criticality-accident literature. See *dose equivalent, sievert.*

rep: An obsolete term for absorbed dose in human tissue, replaced by rad, Originally derived from Roentgen Equivalent, Physical.[1]

risk: The cost of a class of accidents over a given period, usually expressed as dollars or fatalities, per year or during plant lifetime. Unless established by experience, risk is estimated as the product of the probability of occurrence and the consequences of the accident type. Not to be confused with hazard. See *hazard.*

roentgen (R): A unit of exposure; $1\ R = 2.58 \times 10^{-4}$ C/kg in air, where C is coulombs.[3] Strictly, the roentgen applies to x-rays or gamma radiation, although in one report of a criticality accident beta "dosages" are expressed in units of R. See *exposure.*

scram: An alternative term for reactor trip.[1] Reference 6 gives accounts of the origin of this term.

shutdown mechanism: Quenching mechanism and mechanical damage, if any, that limits a prompt-power excursion spike. See *excursion, prompt power; quenching mechanism; spike.*

sievert (Sv): A unit of dose equivalent; 1 Sv = 1 J/kg = 100 rem. Adopted in 1980 by the International Conference on Weights and Measures to replace the rem.[5] See *dose equivalent, rem.*

spike (in a prompt-power excursion): The initial power pulse of a prompt-power excursion, limited by the shutdown mechanism. See *excursion, prompt power; shutdown mechanism.*

tuballoy (Tu): A wartime term for natural uranium, originating in England; now obsolete. See *oralloy.*

uranium enrichment (enrichment): The weight percentage of ^{235}U in uranium, provided that percentage exceeds its natural value; if the reference is to enhanced ^{233}U content, "^{233}U enrichment" should be specified.

x-ray: Electromagnetic radiation of wavelength in the range 10^{-10} cm to 10^{-6} cm.[7]

Criticality Symbols

$\overline{\upsilon\sigma_f}$	effective neutron production cross section
$\overline{\sigma_a}$	effective neutron absorption cross section
$\overline{\upsilon}$	average number of neutrons produced per fission
1/M	1/Multiplication
1/v	inverse of the velocity (sec/meter)
^{235}U	uranium-235
^{237}Np	neptunium-237
^{238}U	uranium-238
^{239}Pu	plutonium-239
^{240}Pu	plutonium-240
^{241}A	americium-241
^{241}Pu	plutonium-241
α-Plutonium	alpha phase plutonium
atom%	atom percent
B	boron
barns	10^{-24} cm^2
C	carbon
Ca	calcium
CaO_2	calcium oxide
Cl	chlorine
D_2O	deuterium oxide (heavy water)
eV	electron volt (1.60219 x 10^{-19}J)
Fe	iron
Gd	gadolinium
η (eta)	the number of neutrons produced per thermal neutron absorption in the fuel
H/^{239}Pu	hydrogen/plutonium-239 ratio
H/Pu	hydrogen/plutonium ratio
H/U	hydrogen/uranium ratio
H/X	hydrogen/nuclide ratio
H_2	hydrogen molecule
k_{eff}	calculated effective manipulation factor
keV	10^3 eV
k_∞	neutrons produced in one generation divided by the neutrons absorbed in the preceding generation
Li	lithium

Criticality Symbols (continued)

Mg	magnesium
MgO	magnesium oxide
ν	number of neutrons emitted per fission
Na	sodium
NaCl	sodium chloride
O	oxygen
Oy	oralloy (highly enriched uranium)
pH	$-\log[H^+]$, a measure of solution acidity
Pu	plutonium
$Pu\text{-}(CH_2)_n$	plutonium-polyethylene
Pu/U	plutonium/uranium ratio
$PuCl_3$	plutonium chloride
σ	neutron cross section
σ_a	absorption cross section
σ_b	capture cross section
σ_f	fission cross section
Si	silicon
SiO_2	silicon oxide
Ti	titanium
U(93)	93% enriched uranium
Zr	zirconium
$[(CH_2)_n]$	polyethylene

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Appendix B
Recommendation 93-2 to the Secretary of Energy

RECOMMENDATION 93-2 TO THE SECRETARY OF ENERGY
pursuant to 42 U.S.C. § 2286a(5)
Atomic Energy Act of 1954, as amended.

Dated: March 23, 1993

The end of the international competition in manufacture of nuclear weapons, and the transition to large scale dismantling of nuclear weapons, have generated strong pressures to reduce the defense nuclear budget and to close down many defense nuclear facilities and operations. At the same time, the development of firm plans for a Complex 21 to serve future nuclear defense needs has slowed. These trends lead to a possibility that capabilities and functions necessary for current and future needs could be terminated along with those no longer required. One of these, important for the avoidance of certain types of accidents, is support of nuclear criticality control.

Because of the importance of avoiding criticality accidents, the Board carefully follows the state of criticality control at DOE's defense nuclear facilities. This interest has been evident as Board members and staff have reviewed practices at the Pantex Plant. The Board believes it is important to maintain a good base of information for criticality control, covering the physical situations that will be encountered in handling and storing fissionable material in the future, and to ensure retaining a community of individuals competent in practicing the control.

In the course of retrenchment of its activities in recent years, the Department of Energy and its predecessor agencies have terminated use of all but one of its general purpose facilities for conducting neutron chain-reacting critical experiments with fissionable material. The research at these facilities had served programmatic purposes of diverse DOE programs, as well as laying a general experimental basis for practices that ensure averting criticality accidents. The Board is informed that there is now a strong possibility that the last DOE facility capable of general purpose critical experiments will be shut down in the near future, due to lack of funding. This possibility arises because no single program of the Department has an overriding need for this remaining facility at the Los Alamos National Laboratory, and therefore no single program office is motivated to provide its financial support in this period of budget stringency. A certain complacency fed by some years of freedom from criticality accidents seems also to underlie this possibility.

The Board observes that the art and science of nuclear criticality control have three principal ingredients. The first is familiarity with factors that contribute to achieving nuclear criticality, and the physical behavior of systems at and near criticality. This familiarity is developed in individuals only through working with critical systems. It cannot be imparted solely through learning theory and using computer codes. The second is theoretical understanding of neutron multiplication processes in critical and subcritical systems, leading to predictability of the critical state of a system by methods that use theory benchmarked against good and well characterized critical experiments.

The third is thorough familiarity of nuclear criticality engineers with the first two factors, obtained through a sound program of training that indoctrinates them in the experimental and theoretical aspects.

The Board has reviewed the status of benchmarking the theoretical methods of criticality control against existing critical experiments and has found that there are notable failures of theoretical analysis to account for the results of a number of experiments. It is not known whether this discrepancy results from inadequate nuclear data used in the analysis or from inadequate care in conducting the experiments and recording their physical features. Both factors could contribute. In addition, it seems that on the average there may be a small non-conservative bias in overall predictions of the theory. In spite of these shortcomings, conservatism in methods used to develop the limits to be applied during handling and storage of fissionable material seems to have led to adequate safety in recent years. The Board believes that in the interest of continued safety it is important to clear up the existing discrepancies, which are obstacles to confident understanding of criticality control. To do so will require conduct of further neutron chain-reacting critical experiments targeted at the major sources of discrepancy between the theory and the experiments, as well as careful analysis of the experiments.

Finally, the Board believes that there is no guarantee that the physical circumstances of handling and storage of fissionable material in the future will always be found in the realm of benchmarked theory. This point is especially important under circumstances that will exist for a number of years to come, with increasing amounts of fissionable material to be stored in a variety of chemical and physical forms. This does not appear to be an appropriate time to eliminate an ability to ensure that such activities will be free of criticality hazard. For safety purposes it will be necessary to retain the capability to perform experiments under conditions not foreseen at this time. This capability once lost would be most difficult to reproduce, and it could be approximated only at great cost and after substantial time, deterring such development even if it were needed badly.

For all the above reasons, the Board believes that continuation of an experimental program of general purpose critical experiments is necessary for continued safety in handling and storing fissionable material. It is needed to improve the basis for the methodology. It is needed as part of the process of properly educating criticality control engineers. It is needed to ensure the capability of answering criticality questions with new and previously unresearched features.

Therefore the Board recommends that:

1. The Department of Energy should retain its program of general purpose critical experiments.

2. This program should normally be directed along lines satisfying the objectives of improving the information base underlying prediction of criticality, and serving in education of the community of criticality engineers.

3. The results and resources of the criticality program should be used in ongoing departmental programs where nuclear criticality would be an important concern.

John T. Conway, Chairman

Appendix C

Request for Criticality Experimental Programs or Criticality Experiments

CRITICALITY EXPERIMENTS WORKGROUP NUCLEAR CRITICALITY TECHNOLOGY AND SAFETY PROJECT (Sponsored by DOE OFFICE OF NUCLEAR SAFETY, POLICY, AND STANDARDS)	REQUEST FOR CRITICALITY EXPERIMENTAL PROGRAMS OR CRITICALITY EXPERIMENTS

Request No.	Title

Date of This Entry	Rev. No.	DOE Contractor

Experiment Category	Application	Status of Request
1 Highly Enriched U **2 Low Enriched U** **3 Plutonium** **4 Pu + U** **5 Transportation** **6 Criticality Physics**	**1 Support New DOE Program** **2 Enhance Current DOE Operation** **3 Resolve Technical Issue** **4 Compliance with DOE Orders** **5 Environmental Issues**	**1 Initial Request** **2 Justification Completed** **3 Justification Being Prepared** **4 Experiment Identified** **5 Anticipated Need** **6 Experiment In Progress** **7 Experiment Complete**

Experiment ☐ Experimental Program ☐

Comments

Requested by	Other Contacts	Priority
		1 Maximum Practical Attention **2 Required for New or Ongoing DOE Operation** **3 Less Urgent than PRIORITY (2)**

Appendix D
Physics Criteria for Benchmark Critical Experiments

Appendix D
Physics Criteria for Benchmark Critical Experiments

April 1990

Workgroup Report, Nuclear Criticality Technology and Safety Project

Workgroup Chairperson: Nancy Landers; Cochairs: Mike Westfall, Brian Koponen

Subject: Physics Criteria for Benchmark Critical Experiments

Item (1) Define the criteria for acceptance of critical and subcritical experiments as benchmarks.

I. For acceptance as a benchmark, the method used to determine k_{eff} should be specified.

II. Consistency among experimentally measured parameters is desirable. For example, the fundamental mode multiplication should be determined by more than one method in order to insure consistency.

III. A rigorous and detailed description of the experimental mockup, its mechanical supports, and its surroundings is necessary. For example, measurements fixing the position of the experiment within the room should be provided. Accompanying photographs and drawings are essential.

IV. A complete specification of the geometry dimensions and material compositions including the methods of determination and the known sources of error and their potential propagation is necessary. Also, for completeness, list unknown but suspected sources of error.

V. A series of experiments is desirable in order to demonstrate the reproducibility of the results. Positive and negative period measurements provide useful supplementary information for well-defined near-critical systems.

VI. A description of the experiment and results, containing at least the elements of the 1983 ANS Standard 8.1, should appear in a refereed publication.

Item (2) Define neutron physics parameters that may be used to classify benchmark experiments by measurement technique.

Physics Parameters

I. Measurements of critical experiments

A. Observation of the multiplication factor of a critical configuration (k_{eff}=1.000)

B. Effective moderator to fissile atom ratio

II. Other than critical measurements

A. Subcritical k_{eff} measurements by one or more methods

B. Pulsed neutron measurements for neutron lifetime and system multiplication and, through delayed neutron fraction and neutron lifetime, source jerk, rod drop, noise analysis, etc.

C. Central worth and replacement measurements

D. Reaction ratios (activation ratios)

E. Reactivity worths

F. Flux traverses—foil or wire traverses

G. Leakage spectra measurements

H. Laplace Transforms, the relaxation length, etc.

I. Neutron source measurements
1. $\bar{\nu}$, the average number of neutrons per fission
2. f, the thermal utilization factor (ratio of thermal neutrons absorbed in the fuel/total thermal neutrons absorbed in the system)
3. η, the number of neutrons produced per thermal neutron absorption in the fuel
4. Spectral measurements (slowing down spectral measurements and thermal scattering kernels)
5. Slowing down time measurements

J. Neutron noise method in time/frequency domain

Item (3) Consider the aspects of present-day computations that are not adequately benchmarked by existing measurements. Define extensions of experimental techniques that may eliminate these deficiencies.

I. Physics parameters that can be calculated (with desired experimental accuracy).

A. Of primary importance and can be calculated directly
1. k_{eff} (within 25%)
2. reaction ratios (5%)(ratios of activities)
3. thermal utilization, η (1%)
4. neutron spectra (5%).

B. Of secondary importance and can be calculated directly.
1. lifetime (5%) (requires kinetics codes)
2. generation time (5%) (requires kinetics codes)
3. number of neutrons per fission (1%)
4. reactivity worths (10%).

C. Parameters of interest requiring extensions of present calculational and/or experimental capabilities.
   1. flux traverses (extend calculational capabilities to reduce uncertainities)
   2. leakage spectrum (extend calculational and experimental capability)
   3. slowing down measurements (extend calculational capabilities)
   4. subcritical measurements (develop calculational capabilities and extend experimental capabilities)
   5. thermal scattering kernels (extend calculational and experimental capabilities)
   6. delayed fission neutron spectra (extend calculational capabilities and enhance experimental capabilities)
   7. time eigenvalues and the effect of time eigen-functions
   8. complex fluxes from neutron wave experiments.

Criticality codes can presently calculate parameters with varying levels of uncertainties that are related to spectral measurements and certain replacement worth measurements. These include: eigenvalue, time to death, time to birth, $\bar{\nu}$, fission production matrix, fluxes, fission densities, the fission energy spectrum, the leakage energy spectrum and reaction rate ratios.

Present day kinetics codes can determine some of the parameters measured in dynamics experiments. However, the present methodology is limited to either point kinetics or diffusion theory.

Item (4) Identify steps that can be made towards standardization in the reporting of benchmark measurements.

The reporting of any experiment intended to be considered a benchmark should include, at a minimum, the relevant portions of the factors listed below. Several of the items are perhaps beyond the capability of even today's relatively sophisticated calculational techniques. However, rather than again fall into the trap of noting only those factors that can be used in contemporary codes, it is possibly preferable to err in "over recording" and "over reporting."

I. A description of the following factors:

A. Fissile materials
   1. Composition
      a. Isotopic analysis
      b. Concentration and density (usually applicable to solutions, but can apply to mixtures such as carbon-uranium) as a function of experimental conditions such as temperature
      c. Impurities: identification, abundance
      d. Departure from stochiometric (e.g., excess acid in solution)
   2. Dimensions (diagrams can help)

B. Associated materials (diluents, grid plates, support structures, control elements, etc.)
   1. Composition
   2. Dimensions and location (diagram)

C. Overall environment (particularly for nominally unreflected measurements; diagram)
   1. Description and location of other materials, fissile and not, in the cell; i.e., tanks, structures, "stored" components, other experiment setups, etc.

   2. Location (diagram), including but not limited to location of experiment with respect to cell walls, floor, ceiling
   3. Document problems such as leaky valves, limited fuel inventory, etc.

D. Programmatic constraints (desirable peripheral information)
   1. Total cost of experiment
   2. Staff/facility requirements
   3. Total program time and time required per measurement

II. "Critical": actual determination or extrapolation (include method of extrapolation, curve, and data)

A. Sensitivity of "control device" (i.e., table position, liquid height, control rod(s) near critical)
B. Experiment conditions, such as temperature, relative humidity, barometric pressure, if relevant and not included as a part of Item I above

III. Experimenter estimate of errors, uncertainties

A. Critical Dimensions
B. Compositions—everything, particularly fissile materials and intimately associated other materials, such as container/support materials
C. Reactivity determinations
D. Reproducibility (independent analyses of material isotopics concentrations, etc., are desirable)
E. Preserve samples for analysis as long as practical
F. Estimate perturbation due to the detectors
G. Measured physics parameters should be compared for internal consistency and for consistency with previously published values

IV. Documentation of auxiliary measurements (including Item III, above)

A. Flux distribution and spectrum measurements
   1. Detector (composition, size, energy, locations, supports)
   2. Perturbation to system (method of determining)
   3. Treatment of raw data (consider archiving of raw data)

B. Rod drop
   1. Geometry of system
   2. Composition, dimensions of rod; location if not specified in Item I.B above
   3. Data and treatment of data, not simply the "answer" (consider archiving raw data)

C. Source jerk
   1. Geometry of system
   2. Source dimensions, composition, strength
   3. Data and treatment of data, not simply the "answer" (consider archiving raw data)

D. Pulse-noise, fixed-source measurements
   1. Description of setup (detectors, source locations)
   2. Description of detectors, source, including dimensions
   3. Data and treatment of data (consider archiving raw data)

Item (5) Identify modifications to application-specific experiments that will permit them to serve as benchmarks.

Criticality experiments have always been an important aspect of nuclear criticality safety. At the inception of the nuclear industry, an experiment could be little more than a replica of the storage vessel arrangement to be employed; often, actual plant items would be used in its construction. This direct approach is still maintained in some laboratories. Almost by definition, the results of such experiments are of limited interest outside the facility concerned. More recently, the importance of criticality experiments to code validation has been recognized. Often the experimental arrangements continue to be application specific. However, they might also be of interest to the wider criticality safety, code validation, and nuclear data evaluation communities. The incorporation of reaction rate measurements will increase their usefulness in this regard.

An integral quantity is k_{eff}. It is possible for a code to calculate k_{eff} correctly for the wrong reasons. The code may, for example, contain canceling errors that may not compensate for one another under different circumstances. Reaction rate measurement allows the validator to examine code performance in terms of event balances in different parts of the neutron spectrum. In an experiment involving low enriched uranium, for example, it might be possible to measure the Fast Fission Ratio (FFR), the ratio of fissions in ^{238}U to those in ^{235}U, and the Relative Conversion Ratio (RCR) the ratio of capture in ^{238}U to fission in ^{235}U. The measured quantities may be compared with reaction-rate ratios given by the code, providing a more stringent test of code performance. The result of such an experiment will provide information that can be included in nuclear cross-section evaluation. As far as the criticality assessor is concerned, confidence in this method of calculation is enhanced.

Item (6) What steps can be taken to insure that data are archived and available to help researchers who may need data that weren't included in the original reporting?

This subject has been considered by the DOE Nuclear Criticality Technology Safety Consultants. To date, little has been accomplished toward this end other than to identify facilities probably having logbooks available for archival, media for storage, mechanisms for storage, and authority for retrieval, distribution and funding of such an endeavor. It was judged that such an endeavor should be delayed for a short time, to permit the currently emerging archival technologies to settle into an accepted and standardized media.

Though there may be substantial information within the "private sector," it was concluded that such information is likely proprietary and not available to a central authority for retrieval, archival and distribution. As such, hope for such an endeavor was hung on retrieving DOE (ERDA, AEC) Contractor critical experiments information via the central authority of DOE. Such an effort seems plausible with proper planning and cooperation of specific critical-experiment, facilities-records custodians and funding. Adequate planning has not occurred to approach the DOE with a formal proposal. However, preliminary efforts have identified the following:

Origin of information

ORNL, LANL, RFP, PNL, UKAEA, BNFL, ANL, KAPL, B&W, SRS, Pratt & Whitney, BNL, Shippingport, AI, MIT, Westinghouse Astronuclear.

Preparation for archival

It was concluded that before information is archived, it should be abstracted and indexed by the originating facility; otherwise, information retrieval will be unwieldy and time consuming. However, we recognize that in many instances archival may not be practical.

Media of archival

The current customary media for easiest archival, distribution and retrieval is microfiche. A growing technology for high-resolution storage and rapid retrieval of such documents is the optical disk memory.

Point of archival

The official archival point for all DOE records is the Office of Scientific and Technical Information (OSTI) in Oak Ridge, formerly the DOE-TIC. Though the final original archival record would be required to be stored at OSTI, an informal record could be made available for central use through a system like the Nuclear Criticality Information System (NCIS). Initial distribution of an archived record could be made through OSTI providing the media of storage is consistent with OSTI's capabilities (currently paper or microfiche or supplied copies of another media). It was determined that further investigations should be pursued with people at the LLNL NCIS Project to assure optimum utilization of the NCIS and its users.

Persons wishing to take an active role in this effort should contact Clint Kolar through the NCIS. A project has been initiated to locate the information, decide what data to archive, and evaluate current technology for storage and retrieval of the information.

Appendix E
Initial Draft of Criteria for Establishing Area of Applicability

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This effort is the result of several days of focused discussion by six to eight criticality analysts and specialists acting on a volunteer basis. It represents their collective considerations on this topic and is offered as guidance for testing and further development. It should not be construed to have any procedural authority. Its intended usefulness is restricted to the context and purpose described above.

Experimental Approach for Code Validation

The criticality safety community has a strong need for critical experiments for multiple purposes. The most pressing need is to perform a series of experiments that would serve as validation for the many computer codes (KENO, MONK, MCNP, etc.) that are widely used in criticality analyses. Validation of codes is an issue that has been debated for some time, but only limited progress has been made. One of the major roadblocks is that the term "area of applicability," as used in ANSI/ANS-8.1, has not been adequately defined. The result is that the community has to use existing experiments and has to try to determine if these experiments can be extended, under "area of applicability," to serve as validation for a particular analysis code. Generally, these experiments were not meant to be used for validation. This has been an exercise with limited results since key definitions do not exist at this time. This appendix contains an initial draft of criteria for establishing "area of applicability."

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There are three conditions which must be satisfied to assure that the calculations done to analyze or support a real situation fall within the "Area of Applicability" for the validation of the code being used. These are: (1) materials, (2) geometry, and (3) neutron energy spectrum.

I. Materials

A. Material Types
1. Fissionable
2. Absorber
3. Moderator
4. Scatterer

B. Criteria (Applicable to all four)
1. Element
2. Isotopic Composition
3. Physical form (metal, solution, compound)
4. Ratio to fissionable material
5. Temperature

II. Geometry

A. Homogenous and Heterogenous
1. Shape
2. Reflection
3. Layering–ordering
4. Relative material thickness

B. Array Criteria
1. Mixed or same type units
2. Number of units
3. Shape of unit
4. Lattice pattern and spacing
5. Interstitial material
6. Reflection
7. Coupling
8. Layering–ordering

III. Neutron Energy Spectrum

A. Neutron density versus energy
1. Leakage
2. Flux

I. Materials

A. Fissionable (all materials of atomic #90 or greater)

Criteria	Tolerance
• Element • Isotopic • Composition	No Tolerance

(Fissionable materials which are present in quantities of less than 0.5% of total fissile material may be neglected)

^{235}U, ^{239}Pu, % ^{235}U, ^{241}Pu	Absolute %
0 - 2	± 1
2 - 5	± 1.5
5 - 10	± 2.5
10 - 20	± 5
20 - 80	± 15
80 - 100	± 10

(If the experimental data point and the actual case fall in different zones, the most conservative tolerance applies.)

% ^{240}Pu (in Pu)	Tolerance	
0 - 32%	± 4%	
• Physical form	No requirement	
• Density as fissionable material	No requirement	
• Density as scatterer	Atom ratio of scatterer to fissionable material must agree ± 5% for extrapolations, ± 20% interpolations	
• Temperature	80°K - 273°K	± 25°K
	273°K - 550°K	± 50°K
	550°K - 1100°K	± 100°K

Moderator	Tolerance
• Element	No tolerance
Isotopes of atomic number less than 12 and low absorption (e.g., excluded ^{3}He, ^{6}Li, ^{10}B, ^{14}N because they are not low absorbers)	Moderating isotopes which are present individually at less than 0.5 atom percent of the total need not be considered moderator. H isotopes need not be considered if present at less than 0.05 atom % of the total moderator.

Moderator	Tolerance
• Isotopic composition	
H	± 20% for interpolation ± 5% for extrapolation
Others	No restriction
• Physical form	No tolerance (the same chemical composition and the same phase)
• Ratio to fissionable material (in fuel region)	Must be present at the same atom ratio with respect to the fissionable material ± 20% for interpolation, ± 5% for extrapolation
• Density (when present in a reflector)	If the element is present in the experiment or the actual case in quantities of greater than 1 w/o, then the experiment and actual case must agree to ± 3 w/o for an extrapolation or ± 10 w/o for an interpolation.
• Temperature	Same as fissionable materials

Absorber	Tolerance
• Element (2 classes)	
1/v (^3He, B^{10}, Li^6)	Interchangeable given the same macroscopic absorption at 2200 m/s.
• Others	No tolerance (isotopes with macroscopic absorption cross sections of less than 10^{-4} cm^{-1} at any energy and an atom ratio with respect to the fissile material of less than 10^{-4} need not be considered.
• Isotopic composition	
1/v (He^3, B^{10}, Li^6)	No additional restriction
• Others	Duplicate the isotopic ratio ± 5%
• Physical form	No restriction
• Ratio to fissionable material	Must be present at the same atom ratio with respect to the fissionable material ± 20% for interpolation, ± 5% for extrapolation
• Density in reflector	If an absorber contributes greater than 1% of the total absorption in the reflector, then atom ratios of the absorber to scatterer and absorber to fissionable, if present, must agree ± 5% for extrapolation, ± 20% for interpolation, and the total absorptions due to the element in the experiment must agree with the actual case to within 15%.
• Temperature	Same as fissionable materials

Absorbers are nonfissionable, nonmoderative isotopes with microscopic absorption cross sections of greater than 2 barns at any energy.

Scatterer	Tolerance
• Material serving as a reflector	Isotope must be present in the experiment and actual case to within ± 10 w/o and the physical density of the actual reflector must agree with the exp. reflector to within ± 25%.
• Material within the fuel region	The atom ratio of the scatterer to fissionable material must agree ± 5% for extrapolation, ± 20% for interpolation.
• Isotopic	
• Physical form	No requirement
• Temperature	Same as fissionable materials

Scatterers include all isotopes which are neither moderators nor absorbers nor fissionable. For isotopes present within a region (either fuel or reflector) at less than 3 w/o in both the actual case and validation, the isotopes need not be considered.

II. Geometry

Homogenous units: Feature	Tolerance
Shape	For non-reentrant bodies, 50% variation on mean cord length calculated as 4* volume/surface For internal reentrant bodies, 25% variation on mean cord length calculated as 4* volume/(internal surface) For external reentrant bodies, no tolerance in shape or size
Reflection	Solid angle to within ± 10% Mean spacing between reflector and fuel ± 10%
Layering/ordering	For systems with multiple material layers, the layer sequence in the experiment and the actual case must be identical
Relative material thickness	Physical thicknesses of all materials must agree to within ± 50%

[homogenous—a single material system or one which combines multiple thin (less than 1 optical thickness) material regions in a uniform pattern (a void is considered a material)]

Heterogenous systems: Feature	Tolerance
Shape of single units	Same as homogenous
Mixed or same type units	For systems which have mixes of material or unit shapes which would be expected to have strong spectral differences within the system, a technical defense must be presented justifying the comparability of the experiment and the actual case
Number of units	The number of units is a coupling concern and is addressed there

Heterogenous systems: Feature	**Tolerance**
Interstitial materials	See layering/ordering and relative material thickness
Reflection	The differential K_{eff} worth of the reflector when comparing the experiment and the actual case must agree within 15% of the differential K_{eff}, for systems where the total reflector worth is less than 0.01 K_{eff}, the reflector comparison need not be considered
Layering/Ordering	Same as for homogenous
Coupling	The sum of all couplings normalized per source neutron must agree to within ± 20%

III. Neutron Energy Spectra

Feature	**Tolerance**
Neutron density versus energy	The normalized neutron production rate averaged overall fuel regions must agree within 0.1% in all 3 energy ranges The absorption and leakage for the complete system must agree within 1.0% in all 3 energy ranges The 3 energy ranges are: 0 - 1 eV 1 eV 100 keV - 20 MeV

Appendix F

Charter
Experiment Needs Identification Workgroup
Nuclear Criticality Technology and Safety Project

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I. Purpose

The purpose of the Experiment Needs Identification Workgroup is to

- Identify new criticality experiments needed to support U. S. nuclear facilities.
- Serve as the national focal point for experiment requests.
- Publish a list of the experiments identified.

II. Scope

The workgroup will identify criticality experiments needed to support the following:

- New U. S. Department of Energy (DOE) programs.
- Modifications to existing DOE facilities.
- Resolution of criticality physics problems.
- Advancement of criticality safety technology.

III. Membership

Membership will be from organizations with a vested interest in nuclear criticality safety, including, but not limited to:

- DOE Contractors DOE Program Offices, and Criticality Safety Committees. The Nuclear Regulatory Commission and Licensees, Critical Mass Laboratories.

IV. Responsibilities

- The Chair coordinates workgroup activities.
- The Vice Chairman serves in the absence of the chairman
- The Secretary prepares and distributes meeting minutes.

Members
- Identify experiment needs.
- Contribute to the Workgroup report.
- Prepare experiment justification statements.
- Attend Workgroup meetings.
- Suggest experiment strategies for ENIWG.

V. Report

A report listing identified experiments will be published through the Nuclear Criticality Information System and updated annually. This report may include input from the Experimental Needs Coordinating Group (ENCOG) regarding experiment priority.

VI. Meetings

The Workgroup will meet annually.

VII. Funding

Participation is voluntary. No funding is provided.

Charter for the EXPERIMENT NEEDS IDENTIFICATION WORKGROUP reviewed and reaffirmed at workgroup meeting on April 28, 1987.

D. A. Rutherford, Chair

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