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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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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.

INTRODUCTION

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.

This document is considered a "living" document and will be updated periodically. A glossary of nuclear criticality terms and a list of symbols (Appendix A), a list of criticality acronyms (page 20), and a list of ENIWG participants (page 24) is found in the Los Alamos report LA-12683.*

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

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*D. Rutherford, "Forecast of Criticality Experiments and Experimental Programs Needed to Support Nuclear Operations in the United States of America: 1994 1999," Los Alamos National Laboratory report LA-12683 (July 1994).

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.

ENIWG OPERATIONS

The function of the Workgroup is to provide the criticality community with a hierarchy of experiments needed to support U.S. DOE, HRC, and its licensees 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

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

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.

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 58 experiments and experimental programs that have been identified and prioritized. The 23 experiments considered highest priority (maximum practical attention) are listed in Table III.

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

Table II: Identified and Prioritized Experiments and Experimental Programs.

Categories		Number of Priority		
		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)	5	2	4
Criticality Physics	(CP)	1	5	1
Total (58)		23	27	8

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*D. Rutherford, "Forecast of Criticality Experiments and Experimental Programs Needed to Support Nuclear Operations in the United States of America: 1994–1999," Los Alamos National Laboratory report LA-12683 (July 1994).

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
	305	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	Establishing the Validity of Neutron-Scattering Kernels
	607	Extending the Standard ANSI/ANS 8.7 to Moderated Arrays
	608	Fission Rate Spectral Index Measurements in Three Assemblies
	609	Validation of Calculational Methodology in the Intermediate Energy Range
CP	702	Spent Fuel Safety Experiments (SFSX)

capability to conduct experiments, or to supervise the temporary staff for particular experiments.

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.

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);

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

- 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.

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
8. (VL&C) Criticality alarm development
9. NEST & START technique development
10. Weapons safety study

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.

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.

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.

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 or 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.

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 5 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.

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*D. Rutherford, "Forecast of Criticality Experiments and Experimental Programs Needed to Support Nuclear Operations in the United States of America: 1994–1999," Los Alamos National Laboratory report LA-12683 (July 1994).