United States Government **Department of Energy**

Memorandum

Idaho Operations Office

Date: July 11, 2006

Subject: Recommendation in response to Task 5 (Appendix A)

To: Jerry McKamy, NNSA
DOE-HQ, NA-171, OFO

This memorandum provides the Criticality Safety Support Group (CSSG) response to Task 5 from the Nuclear Criticality Safety Program (NCSP) manager. The CSSG was tasked to address essential and optional needs in the broad areas of criticality safety support and nuclear data that would require development of a "Super SHEBA" critical solution assembly. The complete text of the tasking is provided as Appendix A.

The CSSG members unanimously support the conclusion that there is a definite need to maintain the capability to perform critical experiments with solutions in the U.S. Discussions from several CSSG meetings are summarized below that indicate the broad range of criticality safety support and nuclear data needs that can only be provided by a device such as the proposed Super SHEBA assembly. Appendix B contains a detailed description of needed capabilities that are now lost with the shutdown of the SHEBA facility. This report was generated by staff of the Los Alamos Critical Experiments Facility who was active in the operation of the Sheba facility over the past decades. Appendix C contains statements of current and anticipated needs from individuals who have been active in major NCSP activities over many years and have a strong awareness of both nuclear data and critical experiment needs.

The CSSG acknowledges that there are experimental resources nationwide, such as university research reactors, and worldwide, such as critical experiments facilities in France, Japan and Russia, that could, in principle, supply some, but not all, of the needs identified in Appendixes B and C. A thorough cost analysis of the capabilities presented by these individual resources was beyond the scope of the tasking and the resources of the CSSG. However, the CSSG was unanimous in its agreement that several key issues made the case both for a Super SHEBA facility as well as the continued operation of the ORELA facility.

Two key issues are clearly defined.

1) Some capabilities are being lost to the DOE that cannot be performed in other countries or with existing U.S. facilities. For example, with the planned, permanent shutdown of the Sandia National Laboratory (SNL) ACRR facility, the NNSA will lose the ability to expose weapons components to radiation environments essential to various programs.

2) It was judged by the CSSG that the U.S. must maintain capabilities within its borders and, indeed, within the DOE, that might be bought from other sources, either in foreign countries or at non-government U.S. facilities. For example, the ability to calibrate criticality accident detectors in an array of physical environments and neutron spectra is

not available at any one location in the U.S. and perhaps at only one foreign location. Having this capability at a dedicated, DOE facility such as a Super SHEBA will assure the U.S. that its R&D and production facilities are not held hostage to the availability or schedules of others. It is also judged that a single Super SHEBA facility would provide a more cost-effective solution to the detector calibration needs of the various U.S. facilities. Similarly, the ability to generate nuclear data within the U.S. would be lost were the ORELA facility, or other equivalent facility, not maintained in an operational state.

Another important, emerging issue that is not well defined at present concerns the nuclear data and benchmark critical experiment needs that will accompany that GNEP program. Clearly there will be the need for much more complete and accurate cross section data on many actinide nuclides as advanced fuel cycles are investigated. Additionally, there will need to be benchmark critical experiments for code validation purposes for solution systems with concentrations of higher actinides far beyond levels previously measured. Further discussion of these needs will be included in the CSSG response to Task 6.

Adolf Garcia
CSSG, Chairman

cc: CSSG Members
J. McKamy, DOE-HQ, NA-171, OFO
J. Felty, SAIC, NA-171, OFO

Appendix A

CSSG Tasking 2006-05

TITLE: Assessment of Criticality Safety and Nuclear Data Needs Requiring a Super-SHEBA Capability

TASKING: The CSSG is requested to identify essential and optional (i.e. essential capabilities/knowledge for safety/efficiency and optional areas that might be useful) needs in the broad areas of criticality safety support and nuclear data that can only be filled by a 'Super-SHEBA.

For each need (essential or optional) identified, a specific DOE program/project/facility that would benefit from the information must also be provided. Such capability will be restricted to pure uranyl nitrate solution experiments, including the ability to perform in burst mode (i.e. prompt critical experiments). It is envisioned that a new 'Super-SHEBA' facility will have the flexibility to tailor experimental vessel(s)/systems to match the needs of the specific experimental program much like the uranium solution experimental program at the Rocky Flats Critical Mass Laboratory.

DELIVERABLE: A formal written report to the NCSP Manager.

DUE DATE: April 30, 2006

Appendix B

Justification for Super SHEBA - TA-18

Specific experiments on a new Super SHEBA to support the Nuclear Criticality Safety Program. (Other issues that need resolution will certainly arise over the years and cannot be anticipated at this time.)

Experiments for the Nuclear Criticality Safety Program

Criticality alarm testing for other DOE and private US companies

Criticality alarm testing is required for any NRC licensed facility that handles nuclear material whenever the existing criticality alarms are modified. The DOE complex also qualifies criticality alarms, but there is no documented requirement. SHEBA (for thermal response) and Godiva (for fast response) have been used to test criticality alarms for LANL TA-55, Portsmouth Gaseous Diffusion Plant, Paducah Gaseous Diffusion Plant, and Y-12. Currently there is no U.S. capability to perform this testing, so modification or upgrade of criticality alarms in NRC licensed facilities is frozen.

Experimental work to understand the dynamics of solution criticality accidents

The latest list of priority experiments for the NCSP contained this set of experiments on the SHEBA assembly. Since SHEBA will not be restarted at TA-18, these experiments could be performed on the Super SHEBA. The regime between 0.90-$ above delayed critical into the prompt critical state has not been characterized.

Evolution of radiolytic gases from solution criticalities

The current SHEBA yielded some interesting preliminary data supporting the idea that the hydrogen evolves first followed some minutes later by oxygen. This could have a significant impact on the response to a solution criticality accident. Also, these results indicate that a solution reactor can be used to produce pure hydrogen with very little effort. This information may be of interest to the hydrogen energy programs as well as programs for space based reactors.

Spent nuclear fuel shipment and burial

The SHEBA assembly was to have made use of the CERES samples to investigate the burn-up credit for spent fuel. This investigation was also on the list of priority experiments for the NCSP. Since SHEBA will not be restarted at TA-18, these experiments could be performed on Super SHEBA

Other cross-section/worth experiments

The SHEBA assembly (and the proposed Super SHEBA) has an experiment cavity in which the neutron spectrum can be tailored to the desired spectra any where from fast to thermal. This feature was used in the past to answer NCSP questions concerning U-233 cross-sections in a timely manner. Measurements on MOX rods were also performed. There will no doubt be other cases where this type of measurement is needed quickly.

Criticality Accidents

The reprocessing of nuclear fuel usually involves the process of chemical separation. This results in the fuel being transformed into a homogeneous aqueous fissile solution. In this form there may be a higher probability of an accidental criticality of the solution, especially while being transported through pipes or stored in vessels. From 1958 to 1970, there were seven accidental supercritical excursions in U.S. processing plants. Initial pulse yields ranged from 10^{15} to 6×10^{17} fissions. Radiation exposure from these accidents ranged from negligible to 1000 rads, and resulted in two fatalities.

Although every effort is made to avoid criticality accidents, the risk of such accidents is never totally eliminated. It is therefore necessary to reproduce and analyze hypothetical accidents through experiments with burst assemblies, such as Super SHEBA. The goal of this work would be a better understanding of solution criticality, excursion dynamics, and shutdown mechanisms. Both prompt burst excursions, lasting milliseconds to tens of milliseconds, and slower "free-run" excursions, lasting tens of minutes, could be examined with Super SHEBA. Fissile solution physical behavior, such as radiolytic gas generation and transient mechanical effects, and neutronic behavior, such as reactivity feedback mechanisms, could be investigated during such excursions. Radiation exposure and detector response experiments could also be performed. It should be noted that any future criticality accident could be the result of a situation not previously considered in accident studies. It is therefore of major importance to try to determine the basic physical mechanisms of such accidents.

Other Programs/Sponsors

It should be noted that an individual program will be unable to fund a Hazard Category 2 Nuclear Facility. In the past, base funding was provided to meet the costs of all of the DOE mandated programs to support a nuclear facility. Within the past year, that funding model has changed leaving the programs to pick up the $4M - $5M a year base cost for even a small nuclear facility. Clearly the NCSP by itself cannot afford to fund experiments on Super SHEBA if this facility model continues and the NCSP is the only program support.

Following is a list of other programs that have funded experiments in SHEBA or have expressed an interest in funding a solution reactor.

Radiation testing of new components to be used at the new CEF in Nevada

The new critical experiments facility being designed for the Nevada Test Site has a number of components and other materials that have not been used at TA-18 and have, therefore, not been subjected to neutron irradiation. Radiation testing of these components is needed to support the CEF design/construction planned to be completed in FY 2010.

Weapon component lethality and vulnerability testing

The LANL Weapons divisions have consulted with TA-18 on numerous occasions to try to replace and/or supplement the capability at the Sandia Pulse Reactor since it will not be available after FY 06.

Weapon computer modeling development

A number of features of the weapons computer models still need benchmark data to validate that portion of the code. A detailed discussion of these features can be provided under separate cover.

Nuclear Chemistry Diagnostics

The Godiva burst assembly was used by the LANL Nuclear Chemistry group to irradiate samples for development of chemical analysis techniques. A burst SHEBA solution assembly could also provide these samples. This program is currently being done in France due to the lack of capability in the U.S.

Non-Proliferation Applications

The Godiva assembly was used to produce a burst of neutrons for development of detection capabilities for non-proliferation and other programs. A solution burst assembly such as Super SHEBA would actually be better for some of these programs since the measurements could be done in the free field to eliminate the backscatter from the concrete buildings.

Program Development Areas

The Global Nuclear Energy Production program is looking toward developing new fuels to produce a closed cycle nuclear power program. This fuel development will result in new solutions being handled that have not been handled historically in enrichment plants. The design of the Super SHEBA, which has modular storage tanks and critical assembly vessels, would allow experiments on these new solutions without any additional hardware costs.

The NASA space reactor programs include a moon-based reactor to produce Hydrogen to be used as fuel. Solution reactors would be a good match for this process.

Appendix C

Statements from Individuals

Mike Westfall (Oak Ridge National Laboratory)

My understanding of the Advanced Fuel Cycle objective is that all of the actinides are recycled back into the fuel stream.

Generally, this involves dissolving the fuel, separating out the fission products, and conditioning the residual fuel back into solid form.

Two situations develop:
1) The higher-mass-number isotopes of plutonium, as well as americium and curium build up.
2) The transition from fluid to solid form in the fuel reprocessing involves systems, which establish intermediate-energy neutron spectra – in which the nuclear data for these actinides are not well known and integral measurements are sparse or non-existent.

The safety basis for efficiently sized equipment, in terms of inventory and throughput, will require the demonstration of safe margins of sub-criticality. This involves the validation of the NCS transport analyses and nuclear data with benchmark critical and/or sub-critical experiments. Certainly, these partially moderated systems, which include the higher actinides, require better differential and integral data to support these validations.

I have attached a rough table of NCS needs for the Advanced Fuel Cycle, which summarizes these issues. The nuclear data testing described above could be performed with both generic critical and sub-critical experiments. Engineering mock-up experiments will also be required to demonstrate the safety of unusual material/geometry combinations in equipment and/or separation/isolation in plant layout.

Potential Criticality Safety Technology Needs Arising from the Implementation of Fuel Reprocessing and Recycling in Advanced Burner Reactors

(Assumed: all actinides go back into fuel, all fission products go into waste stream)

DIFFERENTIAL DATA NEEDS

Transuranic Actinide Data (Cross Sections, Nu, Chi, Decay Data)

- Improved Fuel Exposure Prediction of Spent Fuel Isotopics (Actinides & Fission Products)
- Improved Prediction of Spent Fuel Reactivity Worth for NCS Burnup Credit for More Efficient Sizing & Inventory of Reprocessing Equipment
- Improved Prediction of Neutron Radiation Source Terms, Required Neutron Shielding and Subsequent Neutron Reflection in NCS Evaluations

Improved Nuclide Cross-Section Data for Isotopes Acting as Chemical Reagents (Effects of Neutron Moderation & Absorption)

INTEGRAL DATA NEEDS

Identify, Perform & Verify Critical and Sub-Critical Experiments for Generic Physics and/or Engineering Mockup Applications

- Generic-Physics Critical Experiments to Demonstrate Material Reactivity Effects in Systems with Neutron Spectra Pertinent to These Fuel- Cycle Applications
- Engineering Mock-up Critical Experiments to Demonstrate Capability to Analyze Fuel Cycle Applications with Unusual Material/Geometry Design Features
- Sub-Critical Experiments to Verify the Efficacy of Differential Data in the Analysis of Subcritical Experiments Designed to Simulate Sub-Critical Fuel Cycle Applications

NEUTRON TRANSPORT CAPABILITY NEEDS

Nuclide Separation Process Systems (Wet-& Pyro- Chemistry Processes, Electro-Refining Processes, that is: UREX+, ..., etc.)

- Demonstrate Capabilities for Treating Temperature Effects in Neutron Transport (Neutron Spectra, Absorption Probabilities, Media Densities as Functions of Temperature)
- Application of Sensitivity/Uncertainty Methods & Integral Data to Validate Analytical Capabilities (Transport Methods & Differential Data) Against Pertinent Benchmarks

Advanced Vessel, Storage & Transfer Equipment Geometries

- Geometric Simulation (Efficient Dissolution, Separation Throughput)
- Coupled and/or Single Unit Isolation (Efficient Plant Layout & Maintenance)
- Application of Sensitivity/Uncertainty Methods & Integral Data to Validate Analytical Capabilities (Transport Methods & Differential Data) Against Pertinent Benchmarks

Advanced Fuel Fabrication

- NCS Evaluation of Remote Operations for Highly Radioactive Fuel Fabrication
- NCS Evaluation of Shielded Facilities & Equipment for Storing & Transfer of Highly Radioactive Fuel
- Application of Sensitivity/Uncertainty Methods & Integral Data to Validate Analytical Capabilities (Transport Methods & Differential Data) Against Pertinent Benchmarks

<u>Madeline Feltus</u> (U. S. Department of Energy)

Although the separation chemists may think that they have all the information they need for Uranium and PU/minor actinide separations, and they can "conservatively apply" the ancient test results, we need to be VERY careful about using the historical data we have from previous efforts. The solutions criticality tests at the LANL SHEBA facility used pure uranyl sulfate solutions, Pu solutions, etc, and did NOT have any minor actinides "contaminating" the tests. Theses results may not be suitable for minor actinide bearing solutions, especially with Neptunium, Americium, and further up the periodic table. I would use the following statement as a springboard for discussion, modification etc:

Although criticality experiments have been performed with uranium and plutonium fuels, separate fissile materials, in fuel pin tests and aqueous solution tests (e.g. SHEBA at LANL), the current database does NOT include tests with solutions containing MINOR ACTINIDES that would be present in spent fuel separations activities. Various transuranic isotopes, such as Plutonium Neptunium, Americium, and higher atomic mass elements, will be present in high concentrations as we seek to reprocess spent fuel and recycle fast reactor, deep-burn fuel. Critically benchmark tests, including aqueous solution experiments will be absolutely necessary to assure that criticality safety can be maintained for advanced spent fuel reprocessing,

Hans Toffer (Fluor Government Group, Hanford)

Potential Criticality Safety Technology Needs Arising from the Implementation of Fuel Reprocessing and Recycling in Advanced Burner Reactors

In the planning stages for an Advanced Fuel Cycle Initiative (AFCI), the need for criticality data essential to design considerations has to be firmed up. The AFCI will require facilities where both critical and subcritical measurements can be performed on Plutonium (Pu) and Uranium (U) solutions with and without contaminants. These contaminants can be other actinides, selective fission products, or know additives. The measurement facility should be of dual nature. High precision solution measurement capabilities should be at the Diverse Assembly Facility (DAF). A second facility at the reprocessing plant would provide for quick turnaround measurements for either subcritical or critical solutions. Based on my experience from the Hanford N Reactor the ability to perform measurements on solutions at Hanford was essential to the efficient and safe reactor and reprocessing operation.

Data on Pu – U – other solutions could be procured from other nations, however, such an arrangement could subject the new initiative to undesirable political influences. After all, the basic objective of the new initiative is to support energy independence, therefore control over new reprocessing and supportive data needs has to be domestic.

Use of conservative data on Pu or U solutions would be of some use for initial consideration; however, for detailed design the existing data is too sparse or non-existent especially when it comes to solutions with various elemental mixtures. Use of overly conservative data could limit the efficiency of the new facility. Besides solutions, fuel feedstock materials will require critical/subcritical measurements also.

It is paramount that a decision about critical solution slurry, powder measurement capability for the new initiation be made now. It would take 5 – 7 years before useful data could be obtained from a liquid measurement system at the DAF.

Highest priority has to be assigned to solution measurement capability at the DAF. A commitment is required now for meaningful supportive data for the new fuel cycle.

The above mentioned integral measurements capability is important but of equal significance is the ability to measure differential cross sections of higher actinides and specific fission products. Such data are required for criticality analysis of fuel manufacturing, fuel transport, fuel storage, fuel reprocessing and recycling and waste management.

Blair Briggs (Idaho National Laboratory)

In general it appears that other countries are putting many more resources into improving their nuclear data than we are in the United States. Maintenance and improvement of the U.S. ENDF nuclear data libraries is largely a volunteer effort in the U.S. and has been for decades while other countries have been providing resources for their work.

I offer lead as an example. Lead is widely used in transportation and storage systems for spent nuclear fuels. We have known about deficiencies in the lead cross section for decades. Recently the ICSBEP identified a series of integral experiments that were performed at LLNL that clearly demonstrated an obvious bias when using lead as a reflector. The bias increased as the thickness of lead increased. ICSBEP participants from VNIITF in Russia subsequently offered an independent series of similar experiments that more clearly demonstrated the same bias using U.S. cross section data and MUCH less of a bias using Russian cross section data. The JEFF cross section group immediately dumped resources into re-evaluating the lead cross section and produced a much improved evaluation, even before the Russian benchmarks became available. (I don't know if they included new differential measurements in this case, but they may have.) With a funded staff, they had results for the Russian Benchmarks one weekend (3 days) after I sent them the benchmark. ENDF/B-VII is about to be released. It is my understanding that we will be using the JEFF cross-section data for lead.

With regards to nuclear data, the U.S. is quickly becoming a third world country. That may be an extreme position. Dick McKnight can give you a much more accurate assessment since he works closely with the international community, but my observation is that we are falling behind. My comment is not intended to be a criticism of the efforts of those at BNL, LANL, ANL, ORNL and others who have and continue to volunteer their time to keep us where we are. They have done a remarkable job, but they have not had sufficient resources to do their work since the peak of the reactor development period. Many of the evaluators are aging. The few younger evaluators will likely tire of volunteer work and be attracted to more enticing project that have funding. Begging for funding eventually wears good researchers down. I am not sure that the younger generation will be willing to continue the fight for funding in this manner. Not including resources for Nuclear Data activities on the grounds that we can just be extra conservative is wrong. We need to put resources into both integral and differential measurements.

Lead is an obvious example of a widely used material that we should know much more about. Let me say a few words about plutonium and the higher actinides. The criticality safety community has been struggling with the need for integral benchmark data for damp MOX powders for nearly a decade. The need for integral data for damp plutonium powders has been known for even longer. Existing data has obvious problems. The U.S. lost their capability to do these types integral measurements a long time ago. The OECD NEA sponsored a workshop in the spring of 2004. The experts reached a clear consensus on the need for additional experimental data for these types of systems. The position taken by industry was rather static, thinking only about existing designs and facilities that rely solely on excessive conservatism to compensate for ignorance with little or no concern about future needs. To meet the demands of future United States energy needs, we need dynamic thinking. The static mentality has got us into the situation we are currently in, a super power that either dances to the turn of small oil producing nations or bullies them into giving us what we want.

U.S. integral data for plutonium solutions is generally quite poor. French integral data appear to be much better. The U.S. has lost the capability to perform plutonium solution experiments. Russia has, in large part, relied on U.S. data until the French data became widely available. France is gradually giving up their capabilities and Japan has made a political decision not to allow plutonium into their STACY and TRACY facilities even though that was their original intent and design.

The fact that higher actinide cross sections are, in general, very poor is well documented. As we go to higher burnup, these cross sections will become more important, especially if we start reprocessing the fuel.

With regard to differential data measurement needs, I would refer you to the table in the NCSP Five Year Plan. The NCSP need for Improved Pu-240 cross section data is known. Improved Pu-241 and Pu-242 cross section data are NE needs. We do not know everything there is to know about plutonium. Jerry Cole's preliminary measurements at IPNS on Pu-239 demonstrate that we do not even know everything we think we know about Pu-239. The alpha resonance that he has discovered will likely increase the capture and total Pu-239 cross section over the range of measurement. It will be interesting to see how this discovery will change the performance of our cross section data on certain benchmarks. Even if the effect of this discovery is small for Pu-239, it might not be as small for Pu-240. If we plan to do much with plutonium in the United States in the future, we need Jerry Cole's measurement technique and we need IPNS.

I conclude with a question: By the show of hands, has anyone out there ever built a reactor? Keep your hand(s) up. On the same hand show the number of fingers before you plan to retire. Last year it was GEN-IV, this year it is . . . . If we never really build anything, maybe we won't need more data. Lights out!