December 5, 2014

To: J. N. McKamy Manager, US DOE NCSP
From: Fitz Trumble, Chair, US DOE NCSP CSSG

Subject: CSSG Tasking 2014-04 Response

In Tasking 2014-04 a subgroup of the Criticality Safety Support Group (CSSG) was requested to provide a Review of a LANL proposal for the development, licensing, and construction of a solution experimental capability.

The drafting team consisted of the following CSSG members:
J. A. Morman (lead)
R. W. Wilson
D. K. Hayes
A. Garcia

The attached CSSG response was reviewed by the entire CSSG. Minor comments were incorporated into the final version of the paper that is attached to this memo.

Cc: CSSG Members
G. O. Udenta
M. Dunn
A. N. Ellis
L. Scott

Introduction

According to Tasking 2014-04 (see Attachment 1), *Review of LANL Solution Reactor Proposal*

> The CSSG is directed to use their collective experience to perform a review of that proposal and provide guidance to the NCSP Manager on the proposal from a number of different perspectives.
>
> - Evaluation of the proposed concept for the reactor
> - Extent of added value to the NCSP mission
> - Any enhancements to the proposal that could increase the usefulness, potentially decrease cost/schedule or further leverage the value of the capability to other agencies/programs
> - Possible and most advantageous locations for establishing such an assembly
> - Rough order of magnitude evaluation for the cost and schedule feasibility of the proposal
> - Availability of outside (outside DOE NCSP) interest and funding to support such a capability (cost sharing)
> - Evaluation against the CSSG tasking/response 2006-06 regarding the need for experimental solution capability

This response from the CSSG addresses each of the perspectives given in the tasking statement and provides a summary evaluation based on consideration of each point.

CSSG Evaluation of Tasking Criteria

1) *Evaluation of the proposed concept for the reactor*

The concept as presented in the proposal by LANL[1] (see Attachment 2) is very general but is described as trying to meet the diverse needs of multiple parts of DOE. The reactor is described as being capable of operating in steady state mode for up to several days, but also operating in pulsed mode with super-prompt critical bursts. The use of the proposed solution reactor for medical isotope production is highlighted in the proposal to generate interest from elements of DOE (or other government and private entities) besides criticality safety.

While the multi-purpose approach is commendable, it is not clear that a solution reactor sized to provide a demonstration-scale Tc-99 production system would also be able to meet the flexibility requirements of a solution critical assembly. In addition, limiting the proposed reactor to low enriched uranium solutions would not meet one of the goals stated in previous CSSG tasking responses, namely to restore the U.S. capability to perform experiments with Pu solutions and solutions other than uranyl nitrate.

2) *Extent of added value to the NCSP mission*

Historically, the greatest risk of a criticality accident occurs in solution systems, especially under operational conditions such as blending or stirring. The NCSP has several solid-fuel assemblies to benchmark critical configurations, but it is equally important to have the same capability for solution systems.

[1] "Critical & Subcritical Experiment Design Team Process Proposal, Fissile Solution Critical Experiments," Steven K. Klein, Los Alamos National Laboratory.

The CSSG also noted in 2006 that the US has lost the capability to perform solution experiments, and the joint project to use foreign reactors no longer appears to be a viable option for the future. The Group also concluded that the U.S. must regain the capability for Pu solution experiments. As stated in the response to Tasking 2006-06, "... this capability at a dedicated DOE solution critical experiment facility will assure the U.S. that its R&D and production facilities are not held hostage to the availability or schedules of others."

3) *Any enhancements to the proposal that could increase the usefulness, potentially decrease cost/schedule or further leverage the value of the capability to other agencies/programs*

The most obvious enhancement to the solution reactor is to configure it to use other solutions in addition to LEU. With renewed emphasis on fuel processing technologies a flexible fuel solution reactor could be extremely useful to the complex.

The reactor should be designed as a general purpose machine that can be easily reconfigured for specific research applications such as criticality accident benchmarks, Mo-99 production, minor actinide effects, etc. Note that the reconfiguring for different purposes could be done by changing solutions or simple tank changes without the need to modify the pumps, plumbing, etc. It would be best to propose the best, most flexible system at the start of the project, then reduce options as the design progressed.

4) *Possible and most advantageous locations for establishing such an assembly*

Several criteria must be addressed when identifying potential locations for a solution reactor.

- what type of fuel will be used (U, Pu, HEU, LEU, mixed actinides)?
- what organization/facility will prepare the fuel?
- can the fuel be shipped to the reactor site?
- if used for Tc-99 extraction, where will the post-irradiation separation be done?
- is there a facility at which the reactor be operated under a current safety basis?
- there is a definite benefit to having the reactor located at the NCERC

Obviously, if fissile solutions cannot be shipped over public roads, the reactor would have to be sited within a laboratory that has the capability to produce the solutions. If the liquid fuel can be shipped, the possibilities increase. Also, if any fuel other than LEU is used, security considerations would severely restrict the possible locations.

If the reactor were to be used to demonstrate production of Tc-99, it would be necessary to locate the reactor reasonably close to the separation facility because of the short half-life of the precursor (Mo-99, 2.75 d). Again, depending on the quantities and types of material to be processed, this could also require a Hazard Category 2 hot cell facility.

Based on these considerations, the most likely candidate locations are LANL or the NCERC, but a better-defined proposal is needed to confirm the best probable location.

5) *Rough order of magnitude evaluation for the cost and schedule feasibility of the proposal*

The cost and time estimates given in the proposal for many of the tasks are overly optimistic. Various parts of preparing the safety basis documentation are included in the descriptions of CED-1, -2 and -3. The total costs estimates for these three phases is $1.9M (neglecting materials costs in

CED-3), including preparation of the SDD, final engineering packages, site preparation, installation and testing, and readiness reviews — all in addition to finalizing the safety basis authorization package. This might be reasonable if there were an authorization basis in effect that could be easily modified to cover solution experiments, or if only a small LEU assembly were constructed; however, it is unlikely that such an authorization basis exists that covers critical solution experiments. Based on the time and effort to prepare and approve the authorization documents for NCERC, the paperwork alone could cost double what the proposal estimates. While this conclusion reflects reality, it is indicative of an overly conservative (i.e., not risk informed) regulatory structure.

Based on recent experiences with the cost of LEU fuel for GTRI research reactor conversion projects, it is not unreasonable to expect the fuel alone for this reactor could be $1M or more, a cost not included in the proposal.

Since the entire concept is not defined, there is no cost estimate for the solution handling equipment that would be required to pump, store and possibly purify the fuel solution. Because of the QA requirements associated with nuclear facilities, it is not unreasonable to expect these costs to significantly increase the project cost estimate.

6) *Availability of outside (outside DOE NCSP) interest and funding to support such a capability (cost sharing)*

Depending on the location and capabilities of the reactor, potential contributors could include
- NA-21 (Tc-99 production)
- commercial firms (Tc-99 production and separations technology)
- DOD and associated laboratories (component testing)
- DOE-NE and other offices (reprocessing technology development)
- NNSA and DHS (detector development)
- NRC and licensees (reprocessing technology development)
- international collaborators

7) *Evaluation against the CSSG tasking/response 2006-06 regarding the need for experimental solution capability*

Most of the needs identified in the CSSG responses to Taskings 2006-05 (Super SHEBA) and 2006-06 (Solution Experiments Other than Uranyl Nitrate) are still valid. Some of the needs identified in 2006 are:
- criticality alarm testing for DOE and private US companies
- experiments to
    - understand the dynamics of solution criticality accidents
    - evolution of radiolytic gases from solution criticalities
    - measure cross sections and material worths
- radiation testing of components
- non-proliferation applications
- transuranic actinide data
- support for separation and recycling processes
- temperature effects in solution separation processes

Summary and Conclusions

Since the actual conceptual design of the solution reactor has not been completed, it is not clear whether the proposed concept will meet most of the needs listed above. More details are needed to determine if the requirements of the criticality safety program as well as those of the Tc-99 production program can be simultaneously met.

However, the CSSG is clear in the conclusion that the U.S. DOE needs to restore the capability to perform a wide variety of solution experiments, whether through a major modification to the LANL proposal being considered in Tasking 2014-04 or through a new proposal.

Attachment 1
CSSG Tasking 2014-04

CSSG TASKING 2014-04
Date Issued: August 6, 2014

Task Title: ***Review of LANL Solution Reactor Proposal***

Task Statement:

As part of the FY15 NCSP proposal process, LANL has prepared a proposal for the development, licensing, and construction of a solution experimental capability in the United States. The CSSG is directed to use their collective experience to perform a review of that proposal and provide guidance to the NCSP Manager on the proposal from a number of different perspectives. These shall include:

- Evaluation of the proposed concept for the reactor
- Extent of added value to the NCSP mission
- Any enhancements to the proposal that could increase the usefulness, potentially decrease cost/schedule or further leverage the value of the capability to other agencies/programs
- Possible and most advantageous locations for establishing such an assembly
- Rough order of magnitude evaluation for the cost and schedule feasibility of the proposal
- Availability of outside (outside DOE NCSP) interest and funding to support such a capability (cost sharing)
- Evaluation against the CSSG tasking/response 2006-06 regarding the need for experimental solution capability

Resources:

CSSG Task 2014-04 Team Members:

- Jim Morman, CSSG Team Leader
- Bob Wilson, CSSG
- David Hayes, CSSG
- Adolf Garcia, CSSG

Contractor CSSG members of the team will use their FY14 NCSP CSSG support funding as appropriate; DOE CSSG members of the team will utilize support from their site offices. It is up to the team members to utilize other expertise, or include other interested parties, as can be made available to support the tasking, without incurring additional CSSG expenses. Limited travel may be necessary to support this tasking.

Task Deliverables:

1. CSSG Subgroup to hold task ‘kickoff’ telecom by August 15, 2014
2. CSSG Subgroup to provide draft to full CSSG for review: September 30, 2014
3. Full CSSG to provide review of draft to Task Team Leader: October 11, 2014
4. CSSG Subgroup to provide finalized guidance to NCSP Manager: October 25, 2014

Task Completion Date: October 25, 2014

Signed:
Jerry N. McKamy, Manager US DOE NCSP
Director NA-00-10

Attachment 2
LANL Solution Reactor Proposal

DRAFT

Critical & Subcritical Experiment Design Team Process Proposal
Fissile Solution Critical Experiments

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Introduction

This proposal describes integral experiments required to develop needed data on fissile solution systems. In particular the following broad categories of experiments would be performed. First is the development of data sets related to the operation of solution fueled systems, which are being considered as production sources for a wide variety of industrial and medical isotopes. The second category of proposed integral experiments involve the generation of thermal neutron fields in the full range of possible operations of fissile solution systems including super-prompt critical and steady-state. Such neutron fields would be used for irradiation of a variety of materials including nuclear fuel components, waste forms, items that are of interest from a susceptibility and/or vulnerability perspective, nuclear forensics investigations, training, alarm calibration, and dosimetry. The description of needed critical assemblies, specialized equipment, and fixtures are included in this proposal. In addition, necessary support is described including facilities for the experiments and authorization actions. Finally, projected costs by fiscal year and schedule to implement the proposal are provided.

Background

The third reactor ever built, a fissile solution fueled assembly, LOPO (Low Power), started operation at Los Alamos in 1944 and was used to determine the cross section and critical mass of ^{235}U for the Manhattan Project. Over the next six decades many such assemblies operated at Los Alamos, fueled with both plutonium and uranium solutions. Most were used in direct support of weapons programs but their utility as a reliable and inherently safe source of thermal neutrons was recognized early in their development prompting a wide variety of experimentation in materials science. With the decommissioning of SHEBA in 2004 the U.S. lost domestic testing and research capability employing these versatile machines.

While the historic need for solution fueled assemblies remains, recent interest in aqueous homogeneous reactors (AHR) as they have become known has spiked with the recognition that they offer a safe, reliable, cost effective means to produce radioactive isotopes for nuclear medicine and other applications. The nearly yearlong shut down of NRU reactor followed closely by similar action at Petten exacerbated concern as these two reactors supply approximately 80% of the U.S. need for the important medical isotope Molybdenum-99 (^{99}Mo). The U.S. does not possess any domestic production capability. Along with this isotope supplies of other fission product species, particularly the radioactive iodine family, were greatly diminished. An additional concern is that existing power reactor based production utilizes highly enriched uranium (HEU) with its attendant security concerns. AHR offers an attractive alternative as isotope production by this means may be limited to low enriched uranium fuels. The crisis in medical imaging and therapies caused by this temporary lapse in supply will become critical in 2015 when NRU ceases operation permanently and 2018 when Petten follows suit.

Since the summer of 2009, Los Alamos National Laboratory has been engaged by NNSA Office of Global Threat Reduction (NA-21) to evaluate the feasibility and design of AHR to address the domestic need for ^{99}Mo and other fission products. This effort has resulted in the delineation of design space for fissile solution systems. Fuel types, their characteristics, operational considerations, associated chemistry, neutronic design, safety issues, and the like have all been examined in detail. Both reactor and sub-critical accelerator-driven system designs have been examined. This considerable body of information is now available to directly support the proposed development effort. Of particular relevance is a family of complex models of these systems developed using dynamic system simulation techniques that may be used as a design tool for any such system. Using these techniques several historic reactors, including SUPO, KEWB ("A" and "B" cores), Silene, and HRE have been modeled. The results of this modeling effort show close correlation with historical experimental data across the full range of operation of these real machines. This suggests that systems proposed may be realized in a Rapid Development Environment (RDE) and once produced will operate as advertised. This translates to low technical, cost, and schedule risk.

Development of CED-1 Package

The CED-1 effort must map specific program technical needs to physical equipment. The considerable utility of AHR demands the preliminary design be initiated with a comprehensive set of performance objectives. These objectives will clearly identify the organization of need, a description of need, and broad system requirements to meet each. These objectives will then be mapped into specific technical requirements, drafted in the form of system design descriptions (SDD). Impact of technical requirements on facility and site needs (architecture, infrastructure, and balance-of-plant engineering) as well as safety and authorization basis will be included. Since it is likely that multiple sites, facilities, and design approaches will be possible due to the wide design space of these systems reasonable alternatives will be developed. This body of information will be used to identify technical, cost, and schedule risks inherent in each option. A recommended project approach will be offered.

Regardless of the suite of proposed alternatives, each will utilize the unique characteristics of solution fueled systems: (1) reactivity range from delayed to super-prompt critical with operations in pulsed and steady-state modes; (2) range of shielding options including free-field experimentation, necessary for many issues related to dosimery; (3) maximum use of high-flux thermal neutron spectrum; (4) ability to accept a wide range of samples of both negative and positive reactivity worth in a variety of physical forms; (5) instrumentation and measurement capability for important kinetic parameters.

The basic concept is envisioned to be an AHR employing LEU fissile solution fuel. Auxiliary equipment will include radiolytic gas handling, water makeup, fuel cooling, and controls of sufficient capability to allow long term steady-state and high pulse operations. It is anticipated that much of the design already developed for the isotope production program is directly adaptable to the proposed effort. In addition, the controls and scram systems currently in operation at NCERC may be utilized directly with relatively modest upgrades to current equipment. Finally, the recent work performed for potential commercial customers on hazards and accident analyses and control sets in support of NRC licensing submittals is largely applicable to the proposed equipment. These factors suggest risk factors are largely known and manageable.

Cost & Schedule

The following information has been developed from three sources: (1) historic data on the development and installation of critical assembly machines at NCERC; (2) recent data prepared with private industry partners for commercial installation and operation of isotope production systems; (3) experience in the authorization basis process at candidate facilities. Due to uncertainties in funding cycle and levels the following presents a "best case" estimate of cost and schedule. Downtime due to lapses in funding, inefficiencies due funding trajectory or escalation in material costs are not included as they are unknown. This proposal is crafted within the framework of the NCSP CED process; hence, the following major program milestones apply. The usual definition of each is interpreted in specific context to this proposal.

CED-0: Justification of Integral Experiment Need. This proposal attempts to address most of the issues typical of the CED-0 milestone. However, it is recognized that details may be lacking and a revision will be necessary. For example, inclusion of detailed technical information from the 2011 initiative for the New Silene Critical Assembly may be folded specifically into a revision. Other potential customer needs, outlined below, may be similarly appropriate for inclusion in a revision. Such effort would be expected to be performed this fiscal year as part of the proposal process. *Two months; $20K*

CED-1: Integral Experiments Preliminary Design. This is the bulk of the effort described in this proposal. Major elements include the following: (1) Develop performance specification; *one month; $40K*; (2) Draft technical specification (SDD); one *month; $80K*; (3) Perform site survey; *two months; $80K*; (4) Develop preliminary design package; *two months; $160K*; (5) Develop preliminary hazards and accident analyses and provide safety basis approach; *two months; $40K*; (6) Develop baseline range cost and schedule estimate with associated risk management plan; *one month; $40K*. Since much of this effort may be conducted in parallel the CED-1 effort is assessed as *six months; $440K*

CED-2: Integral Experiments Final Design. Due to the detail work that would be expected to be performed during CED-1 and the leveraging of work already preformed as previously discussed it is expected that this effort may be considerably truncated when compared to wholly new design efforts. Essentially the list of work described in CED-1 above would be finalized into formal baseline documents of a quality that could be used directly for fabrication and initial operations of the proposed system. Additional effort will be required to develop the final engineering packages and to increase the fidelity of associated documentation such as the Authorization Basis data. This will be the major effort involved. A final estimate would be developed during the CED-1 process but based on historical data it is anticipated that a reasonable schedule and cost for this work would be *six months; $660K*

CED-3: Approval to Conduct the Integral Experiment. Under this proposal this effort would include; site preparation; equipment procurement, fabrication, installation and testing; finalization of all authorization documentation and readiness process. Based on NCERC experience this is estimated at *twelve months; $1200K plus $3800K in material*

CED-4: Publication of Data. In this context this is considered as initial operational capability, including fabrication, loading of fuel, and start-up testing. Based on historical experience this is estimated as *six months; $240K + Fuel Cost.* (Fuel cost is not estimated at this time since LEU in metal form may be available within the complex for transfer; preparation of solution fuel costs are included in the $240K).

The following table summarizes the cost and schedule estimates for the proposed effort. (No contingency or escalation has been included in this proposal)

Phase	$K	Months After Start	Fiscal Year Qtr Map (Finish)
CED-0	20	2	4rd FY14
CED-1	440	6	2nd FY15
CED-2	660	6	4th FY15
CED-3	5000	12	4th FY16
CED-4	240	6	2nd FY17
Total	6360	32	

Potential Funding Sources
The following table provides an overview of potential customers who are candidates for use of the proposed capability:

Parent Organization	Division
Non-U.S. Government	IAEA
U.S. Government (non-NNSA)	DOE, DNDO, DTRA, DHS, FBI, DOD, DoS, and Others
NNSA	NA-10, NA-21, NA-22, NA-24, NA-25, NA-40, NA-42, NA-45, NA-47
Private Industry	Nuclear facilities, isotope producers, waste management facilities

It is believed that approximately 50% of the development costs identified as CED-1 & 2 may be available from sources outside NA-10; however, NA-10 assistance will be necessary to obtain this funding.

Summary
The need for an AHR has been long recognized and documented. Today the state of technology development on a variety of solution fueled systems suggests that rapid development and deployment of this capability is feasible.