DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Washington, DC 20004-2901

April 8, 2011

The Honorable Daniel B. Poneman
Deputy Secretary of Energy
U. S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585-1000

Dear Deputy Secretary Poneman:

Seismic analysis and design of high-hazard Department of Energy (DOE) defense nuclear facilities requires evaluation of soil-structure interaction (SSI) effects between the building and its supporting soil. The computer program SASSI (A System for the Analysis of Soil-Structure Interaction) is used extensively for this purpose within the DOE complex, as well as in the commercial nuclear power industry. Recently, SASSI users have identified significant technical and software quality assurance issues with this software. In August 2010, the Los Alamos National Laboratory (LANL) published LA-UR-10-05302, *Seismic Response of Embedded Facilities Using the SASSI Subtraction Method,* identifying issues with the SASSI subtraction method, which is extensively used in DOE's design and construction projects. The Defense Nuclear Facilities Safety Board (Board) is concerned that these issues could lead to erroneous conclusions that affect safety-related structural and equipment design at DOE defense nuclear facilities.

SASSI was developed in 1981 by the University of California at Berkeley (UC Berkeley) as a research tool for performing SSI analysis using the finite element method. It was made publicly available and has undergone revision since its original development, both by UC Berkeley and by various users. Several proprietary versions of the computer program have evolved, based on the source code that was made available by UC Berkeley. However, no central entity supports the use of these various versions of SASSI nor ensures adequate flowdown of software quality assurance requirements from the prime contractors to the sub-contractors who perform SASSI-related work.

During recent analysis of several DOE projects, DOE contractors have identified problems with a particular solution subroutine in the SASSI computer program—the subtraction method. As noted above, LANL structural analysts reported that using the subtraction method for analyzing the LANL Plutonium Facility produced unrealistic seismic responses. To address the problems with the subtraction method, a new modified subtraction method has been proposed by DOE contractors; however, the technical basis for this new approach has not been established. DOE's Chief of Nuclear Safety formed a SSI team with the intent of developing a complex-wide solution to issues associated with the SASSI subtraction method. However, this team comprises

a DOE lead and three outside consultants; it includes no representatives of the National Nuclear Security Administration (NNSA), even though NNSA is responsible for many of the major projects that could be affected by SASSI issues. The Board's staff met with the team on January 19, 2011, to discuss its progress in addressing the SASSI issues. The scope of the team's review is narrow, does not address all of the known issues, and would benefit from assembling additional national experts. It is important for DOE to resolve all of the current issues with the SASSI computer program, as well as to understand and resolve the underlying causes of these issues to prevent future problems from developing.

Therefore, pursuant to 42 U.S.C. § 2286b(d), the Board requests a report and briefing within 45 days of receipt of this letter discussing how DOE intends to address SASSI technical and software quality assurance issues as discussed in the enclosed report by the Board's staff. The requested report should at a minimum: (1) address the need for a root cause analysis of the SASSI issues; (2) address the need for a complex-wide assessment of software quality assurance as it relates to SASSI; (3) address the need for DOE to include outside experts from such organizations as its national laboratories, the nuclear industry, appropriate universities, or the National Academy of Engineering; (4) address how guidance related to SASSI can be formally communicated to DOE projects currently in the design stage; and (5) provide a detailed schedule for corrective actions. The timely resolution of issues associated with SASSI is essential to minimize safety, cost, and schedule impacts to current DOE design projects.

Sincerely,

Peter S. Winokur, Ph.D.
Chairman

Enclosure

c: The Honorable Thomas P. D'Agostino
Dr. Arunava Majumdar
Mrs. Mari-Jo Campagnone

DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Staff Issue Report

March 3, 2011

MEMORANDUM FOR: T. J. Dwyer, Technical Director

COPIES: Board Members

FROM: D. Andersen

SUBJECT: Issues Related to the SASSI Computer Software

This report documents a review by the staff of the Defense Nuclear Facilities Safety Board (Board) of issues related to the computer software SASSI (A System for the Analysis of Soil-Structure Interaction). The SASSI software, which uses the finite element method, is widely used in the Department of Energy (DOE) complex, as well as in the commercial nuclear industry, to determine seismic effects on structures due to soil-structure interaction (SSI). Recently, DOE contractors have identified issues associated with a particular solution subroutine in the SASSI computer program—the subtraction method. To address these issues, DOE has formed a SSI review team consisting of experts in the use of the SASSI computer program. Members of the Board's staff D. Andersen, J. Blackman, B. Caleca, E. Gibson, A. Hadjian, W. Horton, and J. Kimball conducted a review of the team's efforts on January 19, 2011, at the Board's offices. In addition, the staff reviewed numerous reference documents and made project-specific inquires to evaluate SASSI issues.

Based on its review, as documented in this report, the staff concludes that the SSI team's efforts are inadequate given the important role played by the SASSI software in safety-related structural analysis. The team lacks the formality and resources needed to address the identified issues properly and would benefit from assembling additional national experts. Preliminary information provided to the staff suggests that quality assurance for several DOE design projects lack the appropriate level of rigor with respect to the SASSI computer program, its use, and its documentation. Consequently, the Board's staff is concerned that the team's charter does not include software quality assurance (SQA). The staff concludes that it would be advisable for DOE to resolve the issues associated with the SASSI software expeditiously.

Background. SSI analysis is performed to determine the seismic interaction between a structure and its supporting soil; the results of this type of analysis can have a direct impact on the design of safety-related structures and equipment. SSI analysis is especially important for structures embedded within soil or located on sites with a complex soil profile. SASSI, developed in 1981 at the University of California at Berkeley (UC Berkeley), is commonly used for computing the SSI response of most structures being built by DOE, including embedded structures. The original program was based on the doctoral research of four students, and was

modified in 1999 through the doctoral research of a fifth student with the addition of a new solution subroutine—the subtraction method.

The original version of SASSI was made available to the structural engineering community as a research tool. Thus, it and subsequent updates by UC Berkeley were not developed and issued under a formal quality assurance program. The source code was made available by UC Berkeley and has undergone modification by various organizations, resulting in multiple proprietary versions of the software. Several of these proprietary SASSI versions, along with the original UC Berkeley version, are in use in the DOE complex. These versions have been dedicated and maintained under various quality assurance programs.

SASSI performs SSI analysis by analyzing the site and structural response separately and forcing certain levels of coupling between the various substructures: the soil, the excavated soil, and the structure. SASSI's sub-structuring methods are approximate as compared with the full system finite element solution, but require fewer computational resources than the full system solution.

Four main types of sub-structuring techniques can be used in SSI analysis: the rigid boundary method, flexible boundary method, flexible volume method, and subtraction method. Each method involves certain approximations of the site response and interaction problem to reduce the size and complexity of the problem to be solved. The current versions of SASSI include the flexible volume method and subtraction method subroutines. The user's manual specifies the subtraction method as the preferred sub-structuring approach. The subtraction method was originally developed to solve the dynamic response of pile foundations and is more approximate than the flexible volume method. The subtraction method forces interaction only at the interface between the foundation boundary and the native soil, but has the advantage that it is much less computationally demanding than the flexible volume approach. As discussed later, a new sub-structuring technique—the modified subtraction method—has recently been proposed.

SASSI has been used in the nuclear industry for many years. In the DOE complex, the following National Nuclear Security Administration (NNSA) projects have recently or are currently using either the SASSI subtraction or modified subtraction methods:

- Chemistry and Metallurgy Research Replacement (CMRR) Facility, Los Alamos National Laboratory (LANL);
- Uranium Processing Facility (UPF), Y-12 National Security Complex;
- Pit Disassembly and Conversion (PDC) Project, Savannah River Site; and
- Plutonium Facility (PF-4), LANL (as part of DOE's response to the Board's Recommendation 2009-2, *Los Alamos National Laboratory Plutonium Facility Seismic Safety*) (used initially the subtraction method, but now is using the flexible volume method)

The following major DOE projects have completed their SASSI structural analysis:

- Waste Treatment Plant (WTP), Hanford Site;
- Salt Waste Processing Facility, Savannah River Site;
- Highly Enriched Uranium Materials Facility, Y-12 National Security Complex;
- Integrated Waste Treatment Unit, Idaho National Laboratory;
- Device Assembly Facility, Nevada National Security Site; and
- Bays and Cells, Pantex Plant.

Given that SASSI is widely used for safety-related structural analysis of DOE facilities, it is essential that this program conservatively predict structural and equipment demands, and that it comply with the appropriately graded SQA requirements.

SASSI Issues and DOE Actions. In August 2010, LANL issued report LA-UR-10-05302, *Seismic Response of Embedded Facilities Using the SASSI Subtraction Method,* identifying issues with the SASSI subtraction method. The conclusion offered in this report was that the subtraction method produces unrealistic seismic responses when analyzing structures with wide and shallow foundations. These problems were identified because of the appearance of unusual spikes in the analysis transfer functions.

In November 2010, DOE's Chief of Nuclear Safety formed an SSI review team to address issues associated with the SASSI subtraction method. This team comprises a DOE lead reviewer supported by three consultants tasked with finding the cause of the questionable SASSI results and determining a common path forward for DOE projects. The SSI team produced the *SSI Subtraction Modeling Methodology Issue and Evaluation Plan*, which outlines the team's review activities and intended corrective actions. In addition to LA-UR-10-05302, the team was provided several reports, many with conflicting conclusions, which attempt to assess SASSI issues:

- *Response to LANL Report LA-UR-10-05302* [Bechtel National, Incorporated, e-mail communication from F. Ostadan to the American Society of Civil Engineers (ASCE) committee for Standard ASCE-4, *Seismic Analysis of Safety-Related Nuclear Structures,* August 2010]—This report concluded that analysis cutoff frequency, and not the subtraction method, is the source of spurious results. This conclusion indicates that there is disagreement amongst the SASSI experts regarding the source of the unrealistic results.
- *Supplemental Information to LA-UR-10-05302 and Progress Report on Current Activities* (LANL report, September 2010)—According to this report, erroneous results

can be obtained not only with the subtraction method, but also with the modified subtraction method and the flexible volume method.

- CJC-Y12-M-010, *SSI Sensitivity Studies for the UPF Site* (Carl J. Costantino and Associates, November 2010)—This report identifies the subtraction method as the source of erroneous results for the UPF structure and recommends the use of the modified subtraction method.

- *SASSI Study Problem: Direct Method vs. Modified Subtraction Method* (informal calculation performed by Savannah River Nuclear Solutions, LLC, undated)—This is a study of the K-Reactor at the Savannah River Site, where no spurious results were obtained using the modified subtraction method.

- *Examination of SASSI Subtraction Method for Wide Shallow Foundations* (Simpson Gumpertz and Heger, Inc., undated)—This report is a study of a simple, wide, and shallowly embedded rectangular structure. It confirms problems with the subtraction method, and also recognizes inaccuracies in results at high frequencies.

The Board's staff reviewed the SSI team's plan and the reports listed above. The staff found that the reports, in addition to having conflicting conclusions, fail to address the root cause of the issues associated with the SASSI subtraction method. It will be difficult for the DOE SSI team to reach conclusions from these reports. In addition, DOE briefed the staff on the current progress of the SSI team's review on January 19, 2011. The staff makes the following observations about the team composition and technical approach:

- The team appears to be working in an ad hoc manner and lacks sufficient resources. Its plan is too general to address the issues identified to date. Without formality, adequate resources, and a detailed plan for deliverables, the team is poorly positioned to identify and resolve the current problems with SASSI. It is unclear how the SSI team can implement actions such as updating the SASSI user's manual, developing additional SASSI validation problems, and creating a SASSI users' forum without adequate resources and a more formal approach.

- DOE's Chief of Nuclear Safety is coordinating the team. The team includes no individuals representing DOE's Chief of Defense Nuclear Safety, even though many of the current major projects that could be affected by SASSI issues are NNSA projects (CMRR, UPF, PF-4, and PDC).

- The team's charter does not require a root cause analysis of the problems with the SASSI subtraction method. A technical explanation for the problems has yet to be provided.

- The team's charter does not assign responsibilities, authority, or accountability for the team's work and excludes quality assurance from its scope. Numerous users at various locations have altered the SASSI source code, and thus different versions are being used for different DOE projects. The Board's staff does not understand how

configuration management is performed as required by Title 10 Code of Federal Regulations Part 830 Subpart A; *Quality Assurance Requirements,* DOE Order 414.1C, *Quality Assurance*; and American Society of Mechanical Engineers (ASME) Nuclear Quality Assurance (NQA) Standard ASME-NQA-1, *Quality Assurance Requirements for Nuclear Facility Applications.*

- Numerous experts have proposed a modified subtraction method to resolve the problems with the subtraction method. The Board's staff learned that the modified subtraction method is simply the subtraction method with additional interaction nodes at the free surface of the excavated soil volume in the SSI model. However, neither the formal definition nor the technical basis for the modified subtraction method is documented.

- As noted, the reports being reviewed by the team provide conflicting conclusions about the cause of and fixes for the problems with the SASSI subtraction method. The reports make cases for and against both the modified subtraction method and the flexible volume method. In addition, one of these reports states that the issues associated with SASSI relate to the model mesh and cutoff frequency, not the subtraction method. The DOE SSI team is not planning to address this conflicting information.

- A SASSI user identified a problem in analysis of a large number of soil layers affecting a proprietary version of SASSI. The source of the error involves coding common to the original (UC Berkeley) version of SASSI. This issue was documented in *Resolution of the Non-Conformance of the ACS SASSI NQA Version 2.2.1 Software for Application to Deep Soil Deposits* (Dan M. Ghiocel, GP Technologies, Inc., Rochester, NY, September 30, 2009). The DOE SSI team has not been tasked to evaluate the lessons learned (technical or SQA) from this error resolution.

Software Quality Assurance. To further examine SQA as it relates to the use of the SASSI program for various DOE projects, the Board's staff sent sets of comparable SQA questions to representatives of several projects, including CMRR, PF-4, UPF, PDC, and WTP. The intent of these questions was to determine whether project representatives could clearly demonstrate conformance with DOE SQA requirements. After reviewing the information supplied in response to the questions, the Board's staff concludes that there is a wide variation in the way SQA has been applied to SASSI-related work.

As noted above, the original developer of the SASSI program and user's manual was UC Berkeley. Historically, when potential users procured SASSI, they were provided the source code. Over time several users modified portions of the source code to improve the program's capability and performance. The result of this history is that the SASSI software (both code and documentation) has undergone few if any formal SQA procedures (requirements management, configuration management, verification and validation, problem reporting, and corrective action), and, as a result, numerous loosely or uncontrolled versions of the software are in use in the DOE complex. These problems emanate from the lack of a coordinated and integrated approach to managing the SASSI software and controlling changes made to it.

The Board's staff also found that there is no set of documented requirements to use for verification. Nor is there a consistent set of test cases to validate that SASSI meets its requirements and does not perform any unintended functions for the types of design situations being faced today by DOE. The fact that application issues were identified more than 10 years after the subtraction method was introduced suggests that the verification and validation problem sets are inadequate. In addition, there are no comprehensive problem sets to ensure that a potential SASSI user is adequately trained and qualified to use the computer program.

While the Board's staff has not performed a formal SQA review of the SASSI software versions in use, it is clear that the flowdown of SQA requirements from the prime contractors to subcontractors who perform SASSI-related work is inconsistent. Inconsistent or poorly documented SQA requirements can result in uncertain functionality, loss of confidence in the results obtained, poor verification of the requirements, and inadequate validation of the computer program.

This review by the Board's staff indicates the need for a complex-wide DOE position on how to meet safety SQA requirements for SASSI. In a May 5, 2010, letter to DOE, the Board raised the issue of the lack of or inadequate flowdown of quality assurance requirements to a subcontractor performing engineering analysis using a computer program. DOE would benefit by conducting a formal assessment of the flowdown of SQA requirements to subcontractors working with SASSI. Such an assessment would formally review available subcontractor SQA documentation to ensure proper implementation of the SQA requirements of DOE Order 414.1C, Attachment 5, *Safety Software Quality Assurance*, as well as the applicable software requirements of ASME-NQA-1.

Conclusion. Based on its review, the Board's staff concludes that the following actions are needed to address the problems with SASSI as they relate to DOE projects:

- Bring more formality to the DOE SSI team, and perform a root cause analysis of the SASSI problems. To this end, DOE would have to provide adequate resources for the team and revise its review plan to include more detail on deliverables. The root cause analysis would focus on finding the technical cause of the SASSI problems and providing a technical basis for proposed solutions. Expeditious completion of these tasks would support ongoing projects.

- Given the number of NNSA projects currently under design using SASSI, the SSI team would benefit from NNSA's active participation in the team's activities.

- Complex-wide assessment of the adequacy of flowdown of SQA requirements to subcontractors specifically related to SASSI analysis would be advisable. It would also be beneficial for DOE to determine the need for more formal requirements management, configuration management, a verification and validation problem set, error reporting, and corrective actions for SASSI. These activities would enable the sharing of lessons learned and ensure consistency among projects across the DOE complex.