UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

July 8, 2022

MEMORANDUM TO: Ronald G. Ballinger, Lead
SHINE License Application Review Subcommittee
Advisory Committee on Reactor Safeguards

FROM: Jose A. March-Leuba, Member
Advisory Committee on Reactor Safeguards

Jose A. March-Leuba

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Date: 2022.07.08 09:44:54 -04'00'

SUBJECT: INPUT FOR ACRS REVIEW OF SHINE OPERATING LICENSE – SAFETY EVALUATION FOR CHAPTER 13 "ACCIDENT ANALYSIS"

In response to the Subcommittee's request, I have reviewed the NRC staff's safety evaluation report (SER) with no open items, and the associated section of the applicant's final safety analysis report (FSAR), for Chapter 13 "Accident Analysis." The following is my recommended course of action concerning further review of this chapter and the staff's associated safety evaluation.

Background

Chapter 13 of the SER documents the staff's review of the accident analysis performed by the applicant. In this review, I have considered the staff's SER, the SHINE FSAR, the SHINE Safety Analysis Report (TECRPT-2020-16, Revision 1), the responses to Chapter 13 requests for additional information (RAIs) and relevant Chapter 7 RAIs, information in presentations provided by SHINE and the staff at our Subcommittee meetings, and technical reports provided by SHINE.

SER Summary

The SER documents the staff's evaluation of the applicant's design for compliance with applicable regulations and standards. The NRC staff evaluated the descriptions and discussions of SHINE's accident analyses. Based on the above determinations, the NRC staff found that the descriptions and discussions of SHINE's accident analysis are sufficient and meet the applicable regulatory requirements and guidance, and acceptance criteria, for the issuance of an operating license.

SHINE has chosen to use the concept of maximum hypothetical accident (MHA). Using a systematic process hazard analysis and the SHINE safety analysis (SSA), the MHA was identified as the credible fission product-based design basis accident (DBA) which bounds the radiological consequences to the public of all credible fission product-based accident scenarios.

SHINE evaluated the frequency and consequences for a variety of DBAs. Both internal and external events were considered. Results were presented in a risk matrix following the guidance in NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," and NUREG-1520, "Standard Review Plan for Fuel Cycle Facilities License Applications." The DBA based SSA results were used to identify which systems, structures, and components (SSCs) and procedural controls are required to prevent unacceptable consequences. These SSCs are categorized as safety-related.

The acceptance criteria that must not be exceeded are: acute worker dose of 5 rem; acute dose of 1 rem to individuals outside the controlled area; worker intake of 30 mg of uranium; criticality event except in the tank solution vessel (TSV); loss of capability to reach safe shutdown conditions; and acute chemical exposure that would cause either long lasting health effects to a worker or mild transient health effects to individuals outside the controlled area. These criteria are consistent with the applicable regulations.

SHINE's evaluation indicates that the MHA is a large break in the top of the TSV, which allows all radioactive gasses to escape into confinement. After the break is detected and the confinement isolation valves are closed, radioactive gases leak at the technical specification rate, which is periodically verified in accordance with the plant testing and calibration plan. The MHA selection is adequate because it results in the largest possible release of fission products to confinement. Consequences for worker exposure (dominated by control room occupancy) and individuals outside the controlled zone were evaluated to be within the acceptance criteria. The DBA analyses identified that the limiting accident not involving the irradiation facility is a tritium purification system failure, which results in consequences similar to those of the MHA and are within the acceptance criteria.

SHINE hazard analysis documents were not provided on the docket, but they have been made available to the Subcommittee. I find them thorough and well structured, and they support the selection of DBAs used in accident analyses. In several letters, the Committee has expressed a concern that pre-conceived notions or tabulated lists of DBAs not be used for DBA selection. The Committee refers to this concern as "starting from a white piece of paper." The process used by SHINE, satisfies, in my judgment, this concern. In addition, a systematic DBA selection and analyses is a necessary step not only to identify the MHA scenario but also to identify which SSCs are safety related

SHINE's reactor protection system (RPS) performs two main functions: turning off the neutron driver to terminate the fission power (known as driver dropout); and draining the TSV solution to the dump tank. The driver dropout function is equivalent to inserting control rods to shut down a power reactor. The draining-the-TSV function is equivalent to a passive emergency core cooling system (ECCS) because the dump tank is designed to remove decay heat passively to the pool, while the TSV would require active cooling. Note that draining the TSV has the added advantage of ensuring a criticality-safe geometry in the dump tank, which provides a safety function for unexpected scenarios if the TSV reaches criticality.

The SHINE RPS is unusual because it incorporates time delays for actuation of the TSV dump function, while conventional power reactor RPSs actuate immediately. However, this concern is an artifact of incorporating ECCS functions in the RPS. The delays apply only to dump valve actuation to ensure passive decay heat removal when active cooling is lost; driver dropout (equivalent to inserting control rods) is immediate for all events. In power reactors, ECCS actuation may be delayed for minutes or hours; therefore, the SHINE delays are consistent with operating experience. The analyses documented in Chapter 13 indicate that, even accounting for these RPS delays, safety is ensured for all postulated DBAs.

In addition, SHINE incorporates a different type of delay. When the neutron driver drops out (as detected by the measured neutron flux), automatic driver restart is blocked for a period of time to prevent uncontrolled power oscillations due to spurious restarts with a cold, higher reactivity TSV. This delay; however, is an operational concern and does not affect the RPS safety functions.

The SHINE accident analysis does not include a detailed evaluation of operator actions because the facility is designed to automatically shut down the irradiation process, place the target solution into a safe condition, and stabilize accident conditions without immediate operator actions. However, there are possible concerns related to hidden operator actions that were screened from analysis based on the assumptions that the human error probability will be low given administrative controls in place. For example, an operator could inadvertently energize an idle neutron driver resulting in a significant dose to a maintenance worker, but SHINE screened this event as “noncredible” due to the administrative controls and protections in place. Another example is a heavy load drop into an open irradiation unit, which was evaluated as “noncredible” because SHINE applies guidance from NUREG-0612, “Control of Heavy Loads at Nuclear Power Plants: Resolution of Generic Technical Activity A-36.” Another example of concern is recovery from loss-of-cooling and/or power, or driver drops, where the RPS delays discussed above are used to allow the operator for a very quick recovery; as a rule of thumb, quick recovery operator actions are a likely source of errors. In this regard, the staff notes that “since this facility is a first-of-a-kind for which the reliability of human actions has not been studied to the same degree as for power reactors or typical fuel cycle facilities… it is unlikely these indices could be justified without a detailed analysis.” (From Draft Staff SER, Section “Identification and description of safety-related controls to prevent the identified accident sequences or mitigate their consequences”.) While I agree that these events may be properly screened out from the list of DBAs analyzed in Chapter 13, they should be analyzed with some rigor to evaluate the facility risk.

Overall, the referenced documents provide confidence in the systematic approach used by SHINE to identify the challenges to this unique system, the system response to such challenges, and the tools and methods used to predict the system response. Staff evaluations, which included independent calculations of analysis results provided by SHINE, indicate that SHINE evaluations are conservative.

Concerns

My review did not identify any significant deficiencies in the Chapter 13 analysis. However, two areas of concern remain:

1. Operator actions, though not explicitly required to mitigate DBAs, may be a source of risk that must be known to; at a minimum, inform the development of detailed procedures.

2. The Subcommittee was disappointed to hear that staff will not retain the documentation associated with their independent calculations. This requirement may delay staff's ability to respond to future safety issues and may ultimately require the applicant to fund the staff to regenerate this information.

Recommendation

As lead reviewer for Chapter 13, I concur with the staff evaluation that the SHINE's accident analyses are sufficient and meet the applicable regulatory requirements and guidance, and acceptance criteria.

References

1. U.S. NRC, "Accident Analysis," Chapter 13, Staff Safety Evaluation Report, May 16, 2022 (ML22136A302).

2. SHINE Technologies, LLC, Application for Operating License, Supplement 14, Revision to the Final Safety Analysis Report, Chapter 13, Accident Analysis, January 26, 2022 (ML22034A645).

3. SHINE Technologies, LLC, Application for Operating License, Supplement 14, Revision to the Final Safety Analysis Report, Chapter 6, Engineered Safety Features, January 26, 2022 (ML22034A641).

4. SHINE Safety Analysis Report (TECRPT-2020-16, Rev 1).

5. SHINE Medical Technologies, LLC, Application for an Operating License, Response to Request for Additional Information, Chapter 13, August 31, 2022 (ML21243A268).

6. SHINE Medical Technologies, LLC, Application for an Operating License, Response to Request for Additional Information, Chapter 7, March 18, 2022 (ML22077A086).

7. NUREG - 0612, Control of Heavy Loads at Nuclear Power Plants: Resolution of Generic Technical Activity A-36, July 1980.

R. Ballinger

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Package No: ML22164A908
Accession No: ML22175A182 **Publicly Available Y** **Sensitive N**
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