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

September 20, 2023

Chair Christopher T. Hanson
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: REVIEW OF REGULATORY GUIDE 1.183, REVISION 1, "ALTERNATIVE RADIOLOGICAL SOURCE TERMS FOR EVALUATING DESIGN BASIS ACCIDENTS AT NUCLEAR POWER REACTORS"

Dear Chair Hanson:

During the 708th meeting of the Advisory Committee on Reactor Safeguards (ACRS), September 6-8, 2023, we completed our review of Regulatory Guide (RG) 1.183, Revision 1, "Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors." During this meeting, we had the benefit of discussions with representatives of the NRC staff and other stakeholders. We also benefited from the referenced documents.

CONCLUSIONS AND RECOMMENDATIONS

1. RG 1.183 establishes alternative source terms (ASTs) for evaluating design basis accidents (DBAs) at nuclear power reactors. Revision 1 of RG 1.183 provides additional guidance for developing and applying ASTs in DBA dose consequence analysis, addressing new information since Revision 0. Revision 1 should be issued.
2. Because of the need for regulatory stability relative to the use of ASTs (including high burnup and high enriched fuels), a single version (Revision 2) of the regulatory guide should be developed. The schedule for this development should be aligned with the upcoming rulemaking on increased enrichment.
3. Staff should consider detailed comments in this letter related to alignment with emergency preparedness (EP) guidance, rationale associated with the regulatory guide, and the need for capturing lessons learned during implementation.

Background

RG 1.183, Revision 0, "Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors," was issued in July 2000. It was a culmination of extensive research on the timing, magnitude, and chemical form of fission product releases (i.e., source term) from severe reactor accidents in light water reactors (LWRs) following the accident at Three Mile Island, Unit 2. It updates the Technical Information Document (TID)-14844 source term used in siting of LWRs. Revision 1 of this RG addresses the following new issues that have arisen since Revision 0 was issued:

- using the term “maximum hypothetical accident loss of coolant accident” (MHA LOCA) to define the accident described in applicable regulation,
- adding transient release fractions from in-pile reactivity testing and analyses on associated fuel rod performance,
- revising release fractions for accidents other than the MHA LOCA based on a revision to the ANSI/ANS Standard 5.4 for calculating volatile fission product release from oxide fuel,
- adding wording to acknowledge the usefulness of the information in the regulatory guide for advanced LWR design and siting,
- adding guidance for modeling boiling water reactor (BWR) main steam isolation valve (MSIV) leakage and crediting fission product holdup and retention in the main steam lines and condenser,
- adding guidance related to source term analyses for certain accident tolerant fuels (ATFs) and fuels with high burnup and increased enrichment,
- revising transport and decontamination models for a fuel handling DBA, and
- providing additional meteorological assumption guidance.

The RG 1.183 AST is not based on a single accident scenario but is based upon a spectrum of the more likely severe accident events. As used in this regulatory guide, the AST is not representative of the wide spectrum of possible events that make up the planning basis of EP. Therefore, the regulatory guide is insufficient by itself as a basis for requesting relief from the EP requirements. Relevant insights from applicable severe accident research on the phenomenology of fission product release and transport may be considered in analyses that support EP.

Additionally, information on the applicability of this Revision 1 to the new draft RG 1.242 is needed for the recently approved EP rule, Title 10 of the *Code of Federal Regulations* (10 CFR) 50.160, “Emergency preparedness for small modular reactors, non-light-water reactors, and non-power production or utilization facilities.” The present references for draft RG 1.242 do not include the revision number for RG 1.183; hence, confusion could exist due to the co-existence of Revisions 0 and 1 of RG 1.183.

This regulatory guide was originally created for use by the existing LWR fleet. With this revision, the NRC extends the applicability to advanced and passive LWRs to satisfy radiological dose analysis requirements for safety and siting analyses.

Source Term for LOCA Events

Revision 0 of the regulatory guide adopted early melt releases from NUREG-1465, based on accident sequences in NUREG-1150 issued in December 1990. For Revision 1, the MHA LOCA source terms to the containment atmosphere for pressurized water reactors (PWRs) and BWRs (Tables 1 and 2) are updated accident source terms based on results in SAND2011-0128. The tables list core inventory release fractions by radionuclide group for the gap release and early in-vessel release phases of the event. This approach accounts for different inventories at different fuel burnups throughout the operating cycle. Insights from more recent experiments have been considered. For example, the tellurium releases are much higher than the values in Revision 0 of RG 1.183.

Based on new information from Sandia MELCOR analyses (SAND2023-01313), MHA LOCA source terms that are higher than those in Revision 1 have been developed and are being

evaluated for use in Revision 2. It is important for the NRC to engage public stakeholders and industry to provide additional perspective on these results and inform their decision making.

BWR MSIV Leakage

BWR MSIVs are part of the primary containment boundary. Leakage from the MSIVs in postulated accident scenarios would provide a radionuclide source term to the environment. The allowable leakage rate is in the Technical Specifications for the specific plant. Revision 1 to RG 1.183 incorporates lessons learned from recent NRC staff reviews of AST and MSIV leakage License Amendment Requests and provides detailed descriptions acceptable for the evaluation of the source term from MSIV leakage. For example, it provides approaches to model the potential for reduction of the magnitude of release in cases where a system to control MSIV leakage is installed with appropriate redundancy and independence. In addition, it provides detailed guidance for three accurate aerosol deposition methods that are considered acceptable in regulatory positions to be used in conjunction with revised seismic analysis of the piping and related structures, systems, and components (SSCs).

ATF, High Burnup, and Extended Enrichment

The LOCA source terms to the containment atmosphere (Tables 1 and 2) were extended for higher fuel burnups (68 GWd/MTU peak rod-average burnup) and fuel enrichments up to 8 weight-percent uranium-235 based on information from SAND2011-0128. These source terms are acceptable for certain chromium coated zirconium (Zr)-based alloy cladding but are not applicable to mixed oxide (MOX) fuel, doped uranium dioxide (UO_2), coated Zr fuel, fuel with iron, chromium, aluminum (FeCrAl) cladding, or other longer term fuel concepts. At this time, these design features need to be evaluated on a case-by-case basis by the staff.

Source Term for Non-LOCA Events

The regulatory guide provides for steady state release fractions of fission products residing in the fuel rod plenum and gap for non-LOCA events (Tables 3 and 4) available for release upon cladding breach. Appendix I provides an acceptable analysis procedure for calculating plant specific or fuel rod design specific fission product release fractions. The approach is based on a simple Booth diffusion model for volatile fission products accounting for diffusivity in the fuel pellet, surface-to-volume ratio, and isotopic half-life.

For non-LOCA reactivity events that result in a rapid increase in fuel rod power, additional fission product release may occur because of pellet fracturing and grain boundary separation. A transient fission gas release correlation is provided as a function of burnup and increase in radial average fuel enthalpy (in calories/gram) to account for this increase in source term. This source term is added to the steady state release fractions for these events. Given the localized nature of such overpower events, the number of fuel rods and the axial extent of the rods involved are small relative to the entire core.

These source terms are applicable inside a burnup-dependent maximum allowable power operating envelope up to 68 GWd/MTU peak rod average burnup. Applicability to future rod designs including chromium-coated Zr-based alloy claddings, non-Zr claddings, doped UO_2, high-density UO_2, and MOX fuel will be judged on a case-by-case basis.

Alternative Cladding Impact on Source Term

Revisions 0 and 1 do not consider FeCrAl cladding. Of concern with the MHA LOCA melt source term is the tellurium release fraction for the early in-vessel phase of the accident when considering fuel with FeCrAl cladding. The severe accident source term research suggests that the tellurium is bound to the unoxidized Zr alloy cladding in the form of tin telluride (SnTe). The use of FeCrAl cladding will preclude such holdup. In addition, the Zr alloy cladding also chemically binds some of the cesium release from the fuel pellet impacting the cesium release in non-LOCA events. Both the tellurium and cesium release fractions will have to be re-evaluated for cores that use FeCrAl cladding in the future.

Revised Fuel Handling Accident

Appendix B of RG 1.183 addresses analysis protocol for design basis fuel handling accidents. Given their low safety significance, the regulatory guide update provides regulatory relief and operational flexibility when considering fuels with increased enrichment and burnup.

Dose Assessments

Dose assessments that use the TID-14844 source term, such as those conducted in accordance with 10 CFR 100.11, “Determination of exclusion area, low population zone, and population center distance,” employ whole body and thyroid doses as figures of merit instead of TEDE (total effective dose equivalent) per the current 10 CFR 50.67, “Accident source term,” requirements. Each of these dose estimates uses different systems of dosimetry with specific dose conversion factors, and there is no approved methodology to convert between these systems. Revision 1 clarifies that applicants must use the appropriate dose conversion factors associated with the relevant dose figure of merit. In addition, with the use of the AST, the release timing is important in evaluating the dose. To ensure a conservative dose analysis, the guidance states that the period of the most adverse release of radioactive material to the environment should be assumed to occur with the period of most unfavorable atmospheric dispersion (i.e., align the maximum release with the maximum χ/Q values).

Rationale/Intent of Basic Assumptions

The regulatory guide defines a method of analysis that uses a mix of stylized conservative assumptions related to accident progression and ASTs (based on actual data on fission product release from fuel) to establish a representative DBA source term for evaluating the technical adequacy of LWR containment designs and related engineered safety features[1]. The reason for this approach can be traced to the assumptions historically used in analyses that justify site suitability. However, no such explanation is provided in RG 1.183 or in supporting background information linked to the NRC source term information web page[2].

Lack of clarity on how the RG 1.183 guidance is applied to licensing applications was a factor that led to two Differing Professional Opinions (DPOs). One DPO led to redefining the RG scenario as an MHA LOCA. Another DPO led to differing interpretations regarding the safety

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[1] The MHA LOCA as applied in the regulatory guide requires assuming: (1) failure of emergency core cooling systems (ECCS) when determining the fission product release into containment; (2) an end to the fission product release (at the end of the early in-vessel release phase of the severe accident per SECY-94-302); and (3) sufficiently successful ECCS operation to protect containment integrity and justify use of the containment design leak rate assumptions for fission product transport from containment to the environment.

[2] https://www.nrc.gov/reactors/new-reactors/advanced/nuclear-power-reactor-source-term.html

implication of analysis issues. In each of these cases, significant effort was spent determining whether differences in analysis assumptions were significant to safety.

An explanation of both the purpose and limitations of the analysis guidance in this regulatory guide should be provided. For example, an important limitation is that RG 1.183 analyses may not be appropriate for evaluation of more severe accident scenarios with containment failure that may be needed for EP purposes. An explanation of the rationale behind the basic assumptions used in the MHA LOCA, including discussion of the limitations of this DBA method relative to more severe accident scenarios and the need for other analyses to estimate dose consequence in more severe accidents, is needed. Clear documentation of the rationale could also assist in determining the safety significance of any emergent issues identified in a specific analysis. The rationale should be placed in an easily accessible location such as the regulatory guide background section or the source term information web page.

Implementation Concerns

During our review, several concerns were raised by us and other stakeholders relating to the implementation of this regulatory guide including:

- the inability to provide more specific guidance because of differences in the licensing bases for plants in the fleet,
- how to apply the source terms for transition reload cores that have different enrichments and burnups,
- the need to improve Revision 1 guidance for BWR MSIV analysis methods to reduce the chance that errors will occur in the application of the methods or in staff reviews,
- regulatory uncertainty associated with the co-existence of Revisions 0 and 1 of this regulatory guide, potentially leading to unforeseen issues in licensing actions,
- schedule for executing the implementation plan associated with DPO 2021-01 regarding technical aspects of this regulatory guide, and
- new higher MHA LOCA source terms from the fuel based on new information from Sandia MELCOR analyses (SAND2023-01313) that are higher than those in Revision 1 of RG 1.183 and thus could raise a backfit issue if this new information is included in a future single version (Revision 2) of this regulatory guide.

The Office of Nuclear Reactor Regulation management concludes that none of these concerns challenge their determination that an analysis performed per proposed Revision 1 of RG 1.183 would satisfactorily support reactor safety and does not want to delay issuance of Revision 1 of RG 1.183. We agree for the following reasons:

- While these concerns are valid, each application will be carefully evaluated with knowledge of these implementation issues.
- Historically, RGs evolve as additional information and experience is gained. Issuing this revision now will allow capture of lessons learned from associated licensing actions.
- Deferring issuance of this revision to resolve the above concerns could delay fielding of improved fuels in the commercial fleet.

Regulatory stability would be improved relative to the use of ASTs (including for high burnup and high enriched fuels) by developing a single version of this regulatory guide (Revision 2). The schedule for its development should be aligned with the upcoming rulemaking on increased

enrichment. Early issuance of Revision 2 is also important to ensure that direction from the Executive Director for Operations resulting from DPO 2021-01 is carried out expeditiously.

Summary

RG 1.183 establishes ASTs for evaluating DBAs at nuclear power plants. Revision 1 of RG 1.183 provides additional guidance for developing and applying ASTs in DBA dose consequence analysis, addressing new information since Revision 0. Revision 1 should be issued.

Because of the need for regulatory stability relative to the use of ASTs (including for high burnup and high enriched fuels), a single version (Revision 2) of the regulatory guide should be developed. The schedule for this development should be aligned with the upcoming rulemaking on increased enrichment.

An explanation of the rationale for the basic assumptions used in the MHA LOCA, including a discussion of the limitations of this design basis analysis method relative to more severe accident scenarios and the need for other analyses to estimate dose consequence in more severe accidents, is needed.

The applicability of Revision 1 to the new draft RG 1.242 must be clarified to support the recently approved EP rule, 10 CFR 50.160. The present references for draft RG 1.242 do not include the revision number for RG 1.183; hence, confusion could exist due to the co-existence of Revisions 0 and 1 of RG 1.183.

Sincerely,

Signed by Rempe, Joy
on 09/20/23

Joy L. Rempe
Chairman

References

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13. U.S. NRC, SECY-94-302, “Source Term-Related Technical and Licensing Issues Pertaining to Evolutionary and Passive Light-Water-Reactor Designs,” December 19, 1994 (ML003708141).

14. U.S. NRC, Differing Professional Opinion, DPO-2020-002, August 5, 2020 (ML21067A645).

15. U.S. NRC, Differing Professional Opinion, DPO-2021-001, Case File (ML23240A717 Non-Public).

16. U.S. NRC, RG 1.196, “Control Room Habitability at Light-Water Nuclear Power Reactors,” Revision 1, January 2007 (ML063560144).

17. U.S. Code of Federal Regulations, “Determination of Exclusion Area, Low Population Zone, and Population Center Distance,” Title 10, Energy, Section 100.11.

18. U.S. Code of Federal Regulations, “Accident Source Term,” Title 10, Energy, Section 50.67.

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