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MEMORANDUM TO: Kevin Hsueh, Chief
Radiation Protection and Consequences Branch
Division of Risk Assessment
Office of Nuclear Reactor Regulation

FROM: Hossein Esmaili, Chief
H. Esmaili Signed by Esmaili, Hossein on 07/20/21
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Division of Systems Analysis
Office of Nuclear Regulatory Research

SUBJECT: LETTER REPORT ON EVALUATION OF THE IMPACT OF FUEL FRAGMENATION, RELOCATION, AND DISPERSAL FOR THE RADIOLOGICAL DESIGN BASIS ACCIDENTS IN REGULATORY GUIDE 1.183

This memorandum and its attachment addresses the February 24, 2021, Office of Nuclear Reactor Regulation (NRR) informal assistance request (ML21061A000) to Evaluate the Impact of Fuel Fragmentation, Relocation and Dispersal (FFRD) for the Radiological Design-Basis Accidents in Regulatory Guide 1.183, based on NUREG-1465, "*Accident Source Terms for Light-Water Nuclear Power Plants (NUREG-1465),"* specifically the magnitude and timing of the "Containment Source Term" defined in Tables 1, 2, and 4 of this Regulatory Guide. The evaluation also reviewed the Sandia National Laboratories report on an updated accident source term, *Accident Source Terms for Light-water Nuclear Power Plants Using High-Burnup or MOX Fuel*, (SAND2011-0128) which is patterned after the NUREG-1465 Containment source term.

To satisfy the elements of the Information Assistance Request (IAR), staff from the Fuel and Source Term Code Development Branch (FSCB) have prepared the attached letter report that describes the review of the expected impact of FFRD on the Containment Source Term. This report includes:

- A discussion of the regulatory and technical basis for the radiological consequence analysis utilizing the "source term to containment" corresponding to RG 1.183 Tables 1, 2, and 4.

Enclosures:
As stated

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- A discussion of FFRD based on an independent review of the open literature with insights gained from recent Severe Accident PIRT (NUREG/CR-7283).

- Inclusions of necessary technical analyses.

- An assessment of the impact, if any, of FFRD on the RG 1.183 design basis radiological consequence analyses involving significant core damage postulated to occur in conjunction with LOCA events.

- An assessment of the applicability of endorsed codes (ORIGEN*, RADTRAD, and MELCOR) in RG 1.183 for modeling source terms to containment from fuel that fragments.

The assessment documented in the report considered the expected impact of FFRD on the Containment Source Term in Tables 1,2, and 4 of RG1.183 and in subsequent Containment Source Terms derived from MELCOR code calculations reported in SAND 2011-0128. The assessment consisted of a literature review and scoping calculations, where needed. The final attached report incorporates NRR staff comments provided on the final draft.

The analysis concludes that the Containment Source Term in Tables 1, 2, and 4 of RG1.183 is bounding for accident sequences involving FFRD, for the following reasons:

- The analysis supports the expectation that 2% of the fuel fragments and disperses from fuel is likely bounding.

- Only a small fraction of the dispersed fragment mass can reach containment for most scenarios that contribute to core damage frequency.

    - The lower steam velocities during boil-off are not fast enough to overcome settling rates for nearly all of the fragment mass.

    - Larger fragments cannot navigate the tortuous pathway to the containment in most scenarios, unlike far smaller aerosols.

- Dispersed fragments do not have sufficient power to heat themselves, and their surroundings, to the extent that they can release their radionuclides.

    - Fragment decay power is only a small fraction of operating power in most scenarios since they involve several hours between shutdown and the start of core damage (and thus associated fuel fragmentation).

    - Unlike fuel in the core, dispersed fragments are neither directly exposed to the heat from clad oxidation, nor are they surrounded by other hot fuel that prevents radiative cooling.

    - For this reason, FFRD may in fact reduce radionuclide release fractions.

- Some Noble gases can potentially be released earlier in the accident for high burnup fuel. The proportion of early noble gas release depends on its half-life.

- If fragments can collect into dry debris beds, or thick enough submerged debris beds, they can potentially heat up to an extent that they release their volatiles.

    - If fragments collect into debris beds and heat up, the volatiles they release are the same volatiles that would otherwise have been released during the in-vessel phase if they had remained with the rest of the fuel.

- Timing effects from FFRD are small relative to the changes in timing in the current Containment Source Term tables and the changes due to advances in core degradation modeling over the past 20 years.

- Currently endorsed codes (ORIGEN*, RADTAD, MELCOR) are suitable for bounding analyses as is. Refinements can be made to further explore FFRD effects on source term.

* ORIGEN is a SCALE module for isotopic depletion, decay, decay heat, and activation calculations

J. Metcalf's scoping analysis on FFRD effects on ESF leakage, which is reviewed in the report, is attached since it is not otherwise publicly available.

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