Attachment 8

PSAT Calculation 04011H.06

"Source Term for Use on Browns Ferry Application of NUREG-1465"

CALCULATION TITLE PAGE

CALCULATION NUMBER: PSAT 04011H.06

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2	
3	
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Table of Contents

Purpose

The purpose of this calculation is to relate the source terms of Reference 1 to their application to the TVA Browns Ferry Nuclear Power Plant. In addition, a source term for radionulcides other than the important isotopes of the Noble Gasses, iodines, cesiums, and telluriums must be defined in order to be able to evaluate the impact of the "other" radionuclides on the TVA Browns Ferry offsite and control room doses for the DBA LOCA.

Methodology

The application of the revised source terms of Reference 1 to any plant requires the identification of the plant type (PWR or BWR) and a decision as to the time of the start of the gap release. For application to Browns Ferry the plant type is BWR, and for BWRs (according to Reference 1) the time to the onset of activity release (i.e., the start of the gap release phase) would be conservatively established if PWR timing were used. This is what has been done.

To obtain an estimate for the "other" release, the "other" source term from Reference 2 is compared to that from Reference 1 to make a determination of which is more conservative. The most conservative is chosen as the basis for evaluation of the "Other" to dose calculations for Browns Ferry.

Assumptions

Assumption 1: For application to Browns Ferry the PWR timing for the start of release is applied. This timing is approximated by the use of a 30 second delay from the time of reactor shutdown to that of the start of the gap activity release. Once begun, the gap activity release is assumed to be at a uniform rate over the 30 minute duration of the gap release phase.

Justification: By the commentary of Reference 1, this is conservative for Browns Ferry. Reference 1 states that for accidents where long-term cooling of fuel is maintained (e.g.,for a fuel handling accident), the release of the gap activity in failed pins (during the transient overheating of the fuel or immediately after mechanical damage) must be assumed to be instantaneous. This is a reasonable position. It also states that for accidents where long-term cooling is not maintained (e.g., for the 10CFR100 DBA which is the subject of this calculation), the release of the gap activity in the failed pins would be instantaneous, followed by an additional release (equal to 2/3 of the instantaneous release) over the full duration of the "gap release" (that release which occurs prior to the onset of fuel melting). This may be a reasonable position for an individual pin that has been operating at a high power level, but the timing of pin failures and the subsequent temperature rise in individual pins varies across core. This variation needs to be considered, as well as the fact that the magnitude of the gap inventory will not be uniform; i.e., higher burnup pins will, to a degree, exhibit higher gap activity.

According to Reference 1, the failures of the first pin is predicted to occur for PWRs at about 30 seconds after the loss of coolant; other pin failures will follow. A review of some of the analyses supporting Reference 1 (e.g., those listed on Tables 3.1 and 3.2 of Reference 1) indicate that the average core temperature can lag the peak core temperature by many minutes; and while this effect accounts for both radial and axial temperature distributions (and only the radial distribution is significant for the issue of relative timing of pin failures), it still suggests that the assumption of all pins failing in unison at approximately 30 seconds after the loss of coolant accident is excessively conservative.

A more reasonable assumption is one of a uniform release (over the duration of the gap release) totaling 1.67 times the assumed maximum gap inventory available for release at the start of the accident. This takes into account both the progressive nature of the pin failures and the additional release which will occur as pins increase in temperature after failure (but prior to fuel melting). In other words, if one assumes that 3% of the core inventory of a radionuclide of interest is in the gap at the time of the coolant loss, then 5% would be assumed to be released uniformly over the 30 minute duration of the gap release. This would correspond

to a rate of 0.17 % of the core inventory/minute for that radionuclide.

Assumption 2: HI may be neglected in terms of containment behavior and all iodine other than particulate CsI and organic iodine may be considered I_2.

Justification: Reference 3 states that I and HI will coexist and that I will be favored if hydrogen pressures are low and/or if temperatures are relatively high in the location where equilibrium is attained. Specifically, ~~is~~ seven accident sequences studied in Reference 3, the only sequence in which the overall I + HI release exceeded 0.1% of the total iodine was a large break PWR LOCA. For this case, the relatively high temperature gradients within the RCS and the relatively low production of hydrogen (both due to the low steam generation rates characteristic of large break LOCAs) contributed to a relatively high percentage of non-CsI iodine (about 3.2%) but also to a relatively low ratio of HI to I (only 0.4% out of the 3.2%). It should be noted that a large break BWR LOCA was also studied (as one of the other six sequences for which almost no HI or I was found). Given these findings, it is evident that for relatively large release fractions of non-CsI iodine (characteristic of a PWR large break LOCA), little HI will be found, and that for BWRs, even for large break LOCAs, little HI will be found. I_2, on the other hand, has non-RCS sources as well as RCS sources and must be considered even for BWRs. Reference 1 also requires its consideration.

Once in containment, both I_2 and HI are reactive. The solubility of HI, however, is considerably greater than I_2 (nearly 3000 times greater on a molar basis); therefore, one would expect the persistance of HI as an airborne component to be less than I_2 in a steam and water environment. For this reason, as well as for its small release relative to I under the conditions where non-CsI iodine releases occur, it is considered reasonable to treat all non-particulate, non-organic iodine in containment as I_2.

References

Reference 1: Soffer, L., et al., "Accident Source Terms for Light-Water Nuclear Power Plants", NUREG-1465, February 1995

Reference 2: DiNunno, J. J., et al., "Calculation of Distance Factors for Power and Test Reactor Sites", TID-14844, March 1962

Reference 3: Beahm, E. C., et al., "Iodine Chemical Forms in LWR Severe Accidents", NUREG/CR-5732, April 1992

Reference 4: Taylor, J., "Proposed Issuance of Final NUREG-1465, 'Accident Source Terms for Light-Water Nuclear Power Plants'", SECY-94-300, December 15, 1994

Calculation

Specification of Release Phases

Reference 1 describes four release phases: gap, early in-vessel, ex-vessel, and late in-vessel. Reference 4 establishes a precedent for advanced reactors (judged to be applicable to operating plants, as well) that only the first two phases need to be considered for DBA applications. Therefore, two release phases will be referred to: the gap release phase and the fuel release phase, with the fuel release phase making use of only the early in-vessel contribution from Reference 1.

Beginning, Duration, and Release Magnitudes of the Gap Release Phase

By Assumption 1 the gap release starts at 30 seconds and is uniform over time. By Reference 1 the duration of the gap release is 30 minutes. Release magnitudes are as follows (from Reference 1) given as fractions of core inventory and fractions of core inventory per second:

Noble Gas - 0.05 or 2.8E-5 /sec
Iodine* - - - - particulate (CsI) - 0.0475 or 2.6E-5 /sec
- - - - elemental - 2.4E-3 or 1.3E-6 /sec
- - - - organic - 7.5E-5 or 4.2E-8 /sec
Cesium - 0.05 or 2.8E-5 /sec

*Based on 95% particulate, 4.85% elemental (see Assumption 2), and 0.15% organic

Beginning, Duration, and Release Magnitudes of the Fuel Release Phase

This phase begins at 1830 seconds (i.e., at the end of the gap release phase). The duration (from Reference 1) is 1.5 hours for BWRs; therefore, this release phase ends 7230 seconds after the beginning of the accident. Release magnitudes are as follows (from Reference 1) given as fractions of core inventory and fractions of core inventory per second:

Noble Gas - 0.95 or 1.8E-4 /sec
Iodine* - - - - particulate (CsI) - 0.2375 or 4.4E-5 /sec
- - - - elemental - 1.2E-2 or 2.2E-6 /sec
- - - - organic - 3.8E-4 or 6.9E-8 /sec

Cesium - 0.2 or 3.7E-5 /sec
Tellurium - 0.05 or 9.3E-6 /sec

*Based on 95% particulate, 4.85%

elemental (see Assumption 2), and
0.15% organic

To calculate the contribution of "other" radionuclides, consider that Reference 1 provides the following release fractions:

Ba-Sr Group - 0.02
Noble Metal Group - 0.0025
Cerium Group - 0.0005
Lanthanide Group - 0.0002

By comparison, Reference 2 calls for the release of one percent of other radionuclides (other than noble gas and iodine). Since the tellurium and cesium are already being treated separately, it is only the Ba-Sr contribution from Reference 1 that exceeds the specification of Reference 2. On a per unit mass basis the Ba-Sr Group totals approximately 120% of the energy of the other three groups combined (at 5 hours after shutdown, see Reference 3), but the mass available for release is only about seven percent as great (also from Reference 3). Therefore, in combination the other three groups represent more than ten times the energy of the Ba-Sr Group. The fact that the Ba-Sr release fraction in Reference 1 is twice that of Reference 2 is more than compensated for by the fact that the Reference 2 Noble Metal release is four times greater than that of Reference 1, the cerium release is 20 times greater, and the lanthanide release is 50 times greater. Therefore, the one percent release of the "Other" (as presented in Reference 2) will bound the dose effects associated with the release fractions of the "other" from Reference 1 for those dose effects where energy is a good measure of importance (e.g., external whole body dose). For this reason, the one percent release of the "Other" will be used to show that the "Other" has no impact on whole body dose. The specified release of the "Other" is as follows (during the fuel release phase):

Other - 0.01 or 1.9E-6 /sec

Results

Fraction of core inventory, 0 - 30 seconds: no releases

Fraction of core inventory, 30 - 1830 seconds: Gases - Noble Gas - 2.8E-5 /sec (0.05 total)
Elemental I - 1.3E-6 /sec (2.4E-3 tot)
Organic I - 4.2E-8 /sec (7.5E-5 total)

Aerosols - Iodine - 2.6E-5 /sec (0.0475 total)
Cesium - 2.8E-5 /sec (0.05 total)

Fraction of core inventory, 1830 - 7230 seconds: Gases - Noble Gas - 1.8E-4 /sec (0.95 total)

Elemental I - 2.2E-6 /sec (1.2E-2 tot)
Organic I - 6.9E-8 /sec (3.8E-4 total)

Aerosols - Iodine - 4.4E-5 /sec (0.2375 total)
Cesium - 3.7E-5 /sec (0.2 total)
Tellurium - 9.3E-6 /sec (0.05 total)
Other - 1.9E-6 /sec (0.01 total)

Conclusions

The source term specification based on Reference 1 has the following characteristics:

1. Two release phases: a Gap Release Phase beginning at t=30 seconds, lasting 1800 seconds, and a Fuel Release Phase beginning at t=1830 seconds, lasting 5400 seconds.

2. Iodine is in either particulate (dominant, as CsI aerosol) or in gaseous form (as I_2 or organic).

3. One percent of the non-noble gas, iodine, cesium, and tellurium radionuclides are released (i.e., the "Other") in order to bound the actual release fractions of Reference 1 in terms of impact on whole body dose. Note that the "Other" is specified only to verify the assumption that its inclusion in the dose calculation will have little or no impact. It should not be included in calculations of record unless its contribution is negligible.