15.7 Radioactive Release from a Subsystem or Component

This group of events includes the following:

- Gas waste management system leak or failure
- Liquid waste management system leak or failure (atmospheric release)
- Release of radioactivity to the environment via liquid pathways
- Fuel handling accident
- Spent fuel cask drop accident

15.7.1 Gas Waste Management System Leak or Failure

The AP600 gaseous radwaste system is a low-pressure, low-flow charcoal delay process. Failure of the gaseous radwaste system results in a minor release of activity that is not significant. The Standard Review Plan no longer includes this event as part of the review. Therefore, no analysis is provided.

15.7.2 Liquid Waste Management System Leak or Failure (Atmospheric Release)

The AP600 liquid radwaste system tanks do not contain significant levels of gaseous activity because liquids expected to contain gaseous radioactivity are processed by a gas stripper before being directed to storage. The tanks are open to the atmosphere so that any evolution of gaseous activity is continually released through the monitored plant vent. The Standard Review Plan no longer includes this event as part of the review. Therefore, no analysis is provided.

15.7.3 Release of Radioactivity to the Environment Due to a Liquid Tank Failure

Tanks containing radioactive fluids are located inside plant structures.

In the event of a tank failure, the liquid would be drained by the floor drains to the auxiliary building sump. From the sump, the water would be directed to the waste holdup tank. The basemat of the auxiliary building is 6-feet thick, the exterior walls are 3-feet thick, and the building is seismic Category I. The exterior walls are sealed to prevent leakage. Thus, it is assumed that there is no release of the spilled liquid waste to the environment. However, the Standard Review Plan states that credit cannot be taken for liquid retention by unlined building foundations. Analysis of the impact of this event is the responsibility of the Combined License applicant. This analysis should include consideration of tank liquid level, processing and decay of tank contents, potential paths of spilled waste to the environment, as well as other pertinent factors.

15.7.4 Fuel Handling Accident

A fuel handling accident can be postulated to occur either inside the containment or in the fuel handling area inside the auxiliary building. The fuel handling accident is defined as the dropping of a spent fuel assembly such that every rod in the dropped assembly has its cladding breached so that the activity in the fuel/cladding gap is released.

The fuel handling accident analysis takes into account both the initial release to the environment of noble gases and the portion of the iodines that are not retained in the cooling water pool, and the release of iodines from the pool of water resulting from the postulated simultaneous loss of cooling to the water pool.

The possibility of a fuel handling accident is remote because of the many administrative controls and the equipment operating limits that are incorporated in the fuel handling operations (see subsection 9.1.4). Only one spent fuel assembly is lifted at a time, and the fuel is moved at low speeds, exercising caution that the fuel assembly not strike anything during movement. The containment, auxiliary building, refueling pool, and spent fuel pool are designed to seismic Category I requirements to thus provide their integrity in the event of a safe shutdown earthquake. The spent fuel storage racks are located to prevent a credible external missile from reaching the stored fuel assemblies. The fuel handling equipment is designed to prevent the handling equipment from falling onto the fuel in the reactor vessel or that stored in the spent fuel pool. The facility is designed so that heavy objects, such as the spent fuel shipping cask, cannot be carried over or tipped into the spent fuel pool.

15.7.4.1 Source Terms

15.7.4.1.1 Initial Airborne Release Source Term

The inventory of fission products available for release at the time of the accident is dependent on a number of factors, such as the power history of the fuel assembly, the time delay between reactor shutdown and the beginning of fuel handling operations, and the volatility of the nuclides.

The fuel handling accident source term is derived from the core source term detailed in Appendix 15A by taking into account the factors below. The assumptions used to define the fuel handling accident initial airborne release source term are provided in Table 15.7-1 along with the derived source term.

15.7.4.1.1.1 Fission Product Gap Fraction

During power operation, a portion of the fission products generated in the fuel pellet matrix diffuses into the fuel/cladding gap. The fraction of the assembly fission products found in the gap depends on the rate of diffusion for the nuclide in question as well as the rate of radioactive decay. In the event of a fuel handling accident, the gaseous and volatile radionuclides contained in the fuel/cladding gap are free to escape from the fuel assembly. The radionuclides of concern are the noble gases (kryptons and xenons) and iodines. Based on NUREG-1465 (Reference 1), the fission product gap fraction is 3-percent of fuel inventory. For this analysis, the gap fraction is increased to 3.6 percent of the inventory to address concerns identified in NUREG-1465 regarding the applicability of the 3-percent gap fraction to high burnup fuel (that is, fuel with burnup in excess of 40 gigawatt days per metric ton of uranium).

15.7.4.1.1.2 Iodine Chemical Form

Consistent with NUREG-1465 guidance, the iodine is assumed to be 95-percent cesium iodide, 4.85-percent elemental iodine, and 0.15-percent organic iodine. There is no organic iodine present in the fuel itself. The organic iodine is assumed to be formed from the reaction of elemental iodine with organic contaminants in the spent fuel pool.

15.7.4.1.1.3 Iodine Behavior in the Gap

Cesium iodide is nonvolatile, and the iodine in this form dissolves in water but does not readily become airborne. It is assumed that the cesium iodide is not entrained in the air bubbles released from the damaged fuel assembly. Although elemental iodine is expected to plate out on the relatively cold surfaces of the fuel cladding instead of remaining airborne, it is conservatively assumed that the elemental iodine in the gap remains as an airborne component.

15.7.4.1.1.4 Assembly Power Level

All fuel assemblies are assumed to be handled inside the containment during the core shuffle so a peak power assembly is considered for the accident. Any fuel assembly can be transferred to the spent fuel pool; during a core off-load, all fuel assemblies are discharged to the spent fuel pool. For obtaining a bounding condition for the fuel handling accident analysis, it is assumed that the fuel handling accident involves a fuel assembly that operated at the maximum rated fuel rod peaking factor. This is conservative because the entire fuel assembly does not operate at this level.

15.7.4.1.1.5 Radiological Decay

The fission product decay time experienced prior to the fuel handling accident is at least 100 hours.

15.7.4.1.2 Source Term for Releases from a Boiling Spent Fuel Pool

It is conservatively assumed that coincident with the fuel handling accident, there is a loss of spent fuel pool cooling resulting in boiling of the water in the spent fuel pool. As the water boils, a portion of the iodine in the water would be released to the environment. It is assumed that all of the gap iodine activity from the damaged fuel assembly that was not released to the environment immediately is in the water pool and is available for release due to the pool boiling. The iodine source term for pool boiling releases is provided in Table 15.7-1.

15.7.4.2 Release Pathways

The spent fuel handling operations take place underwater. Because of this, activity releases are first scrubbed by the column of water 23 feet in depth. This has no effect on the releases of noble gases or organic iodine but there is a significant removal of elemental iodine. Based on tests, the scrubbing provided by a 23-foot column of water reduces the concentration of elemental iodine in the gas bubbles by a factor of greater than 500 (Reference 2). For the fuel handling accident analysis, the pool scrubbing decontamination factor is assumed to be 133, which is far less than the value supported by tests. The decontamination factor of 133 for elemental iodine is consistent with the guidance in Regulatory Guide 1.25.

After the gases released from the fuel assembly escape from the water pool, it is assumed that they are released directly to the environment within a 2-hour period without credit for any additional iodine removal process.

If the fuel handling accident occurs in the containment, the release of activity can be terminated by closure of the containment purge lines on detection of high radioactivity. No credit is taken for this in the analysis. Additionally, no credit is taken for removal of airborne iodine by the filters in the containment purge lines.

For the fuel handling accident postulated to occur in the spent fuel pool, there is assumed to be no filtration in the release pathway. Activity released from the pool is assumed to pass directly to the environment with no credit for holdup or delay of release in the building.

Coincident with the fuel handling accident, it is assumed that there is a loss of spent fuel pool cooling capability. The water in the pool is assumed to contain the total fuel assembly gap inventory of iodine that was not released to the environment by the initial fuel handling accident. The iodine that becomes airborne due to pool boiling is assumed to go directly to the environment.

15.7.4.3 Dose Calculation Models

The models used to calculate doses are provided in Appendix 15A.

Table 15.7-1 lists the assumptions used in the analysis.

15.7.4.3.1 Differences from the Guidance of Regulatory Guide 1.25

The significant differences from Regulatory Guide 1.25 are discussed below.

15.7.4.3.1.1 Gap Fraction

The gap fraction specified in Regulatory Guide 1.25 is 10 percent for short-lived nuclides and 30 percent for long-lived nuclides. The assumption used in the fuel handling accident analysis of 3.6 percent is based on the guidance of NUREG-1465, as discussed in subsection 15.7.4.1.1.

15.7.4.3.1.2 Iodine Chemical Form

In Regulatory Guide 1.25, it is assumed that 99.75 percent of the iodine is in the elemental form and that the remaining 0.25 percent is in the organic form.

The assumption of 95-percent cesium iodide, 4.85-percent elemental, and 0.15-percent organic is consistent with the iodine characterization defined by NUREG-1465 (Reference 1).

15.7.4.3.1.3 Iodine Dose Conversion Factors

The thyroid dose conversion factors specified in Regulatory Guide 1.25 are taken from TID-14844 (Reference 3), and these values are derived from material in ICRP Publication 2 (Reference 4).

With the change in accident dose methodology to calculate total effective dose equivalent (TEDE) doses instead of thyroid and gamma whole body doses, the use of thyroid dose conversion factors is no longer used. The TEDE doses are a combination of the committed effective dose equivalent (CEDE) doses and the gamma whole body doses. The CEDE dose is calculated using dose conversion factors based on EPA Federal Guidance Report No. 11 (Reference 5), which include contributions from the significant organ pathways, including the thyroid.

15.7.4.3.2 Identification of Conservatisms

The fuel handling accident dose analysis assumptions contain a number of conservatisms. Some of these conservatisms are described in the following subsections.

15.7.4.3.2.1 Fuel Assembly Power Level

The source term is based on the assumption that all of the fuel rods in the damaged assembly have been operating at the maximum fuel rod radial peaking factor. In actuality, this is true for only a small fraction of the fuel rods in any assembly. The overall assembly power level is less than the maximum radial peaking factor.

15.7.4.3.2.2 Fission Product Gap Fraction

The assumption of 3.6-percent gap fraction for the short-lived nuclides is conservative by a factor of 2 or more, depending on the nuclide.

15.7.4.3.2.3 Amount of Fuel Damage

It is assumed that all fuel rods in a fuel assembly are damaged so as to release the fission product inventory in the fuel/cladding gap. In an actual fuel handling accident, it is expected that there would be few rods damaged to this extent.

15.7.4.3.2.4 Iodine Plateout on Fuel Cladding

Although it is expected that virtually all elemental iodine plates out on the fuel cladding and is unavailable for atmospheric release, no credit is taken for plateout.

15.7.4.3.2.5 Pool Scrubbing Decontamination Factor for Elemental Iodine

The selection of a scrubbing decontamination factor of 133 provides a factor of approximately four conservatism in determining iodine releases based on the pool scrubbing test data (Reference 2).

15.7.4.3.2.6 Meteorology

It is unlikely that the conservatively selected meteorological conditions are present at the time of the accident.

15.7.4.3.2.7 Time Available for Radioactive Decay

The dose analysis assumes that the fuel handling accident involves one of the first fuel assemblies handled. If it were one of the later fuel handling operations, there is additional decay and a reduction in the source term.

15.7.4.4 Offsite Doses

Using the assumptions from Table 15.7-1, the calculated doses from the initial releases are determined to be 1.5 rem TEDE at the site boundary and 0.3 rem TEDE at the low population zone outer boundary. Because of the time required to reach boiling in the spent fuel pool after loss of cooling, there is no contribution to the 2-hour site boundary dose from the postulated pool boiling releases. The dose at the low population zone outer boundary due to pool boiling releases is calculated to be 1.0 rem TEDE based on a 30-day duration of pool boiling.

The total doses associated with the fuel handling accident are thus 1.5 rem TEDE at the site boundary and 1.3 rem TEDE at the low population zone outer boundary. These doses are well within the dose guideline of 25 rem TEDE identified in 10 CFR Part 50.34. The phrase "well within" is taken as meaning 25 percent or less, consistent with the Standard Review Plan.

15.7.5 Spent Fuel Cask Drop Accident

The spent fuel cask handling crane is prevented from travelling over the spent fuel. No radiological consequences analysis is necessary for the dropped cask event.

15.7.6 Combined License Information

Combined License applicant referencing the AP600 certified design will perform an analysis of the consequences of potential release of radioactivity to the environment due to a liquid tank failure as outlined in subsection 15.7.3.

15.7.7 References

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

2. Malinowski, D. D., et al., "Radiological Consequences of a Fuel Handling Accident," WCAP-7828, December 1971.

3. DiNunno, J. J., et al., "Calculation of Distance Factors for Power and Test Reactor Sites," TID-14844, March 23, 1962.

4. "Report of ICRP Committee II on Permissible Dose for Internal Radiation," International Commission on Radiological Protection, ICRP Publication 2, 1959.

5. Eckerman, K. F., et al., "Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion," EPA Federal Guidance Report No. 11, EPA-520/1-88-020, September 1988.

Table 15.7-1 (Sheet 1 of 2)

ASSUMPTIONS USED TO DETERMINE FUEL HANDLING ACCIDENT RADIOLOGICAL CONSEQUENCES

Source term assumptions	
– Core power (MWt)	1972
– Decay time (hr)	100
Average fuel assembly source term after 100 hours decay (Ci)	
I-131	2.7 E+05
I-132	2.2 E+05
I-133	2.7 E+04
Xe-131m	3.7 E+03
Xe-133m	9.5 E+03
Xe-133	5.1 E+05
Xe-135	9.5 E+02
Kr-85	6.7 E+03
Maximum rod radial peaking factor	1.65
Percentage of fission products in gap	3.6
Iodine chemical form (%)	
– Elemental	4.85
– Organic	0.15
– Particulate	95
Source term for gaseous release from the failed fuel assembly (Ci)[(a)]	
I-131	8.0 E+02
I-132	6.55 E+02
I-133	8.0 E+01
Xe-131m	2.2 E+02
Xe-133m	5.64 E+02
Xe-133	3.03 E+04
Xe-135	5.64 E+01
Kr-85	3.98 E+02
Pool decontamination factor for elemental iodine	133
Initial activity release period (hr)	2
Atmospheric dispersion factors	See Table 15A-5 in Appendix 15A

<u>Note:</u>

a. Only the elemental and organic forms are volatile and available for airborne release.

Table 15.7-1 (Sheet 2 of 2)

ASSUMPTIONS USED TO DETERMINE FUEL HANDLING ACCIDENT RADIOLOGICAL CONSEQUENCES

Breathing rates (m^3/sec)	
– 0 - 8 hours	3.47E-4
– 8 - 24 hours	1.75E-4
– >24 hours	2.32E-4
Nuclide data	See Appendix 15A
Pool boiling assumptions and parameters	
– Initial iodine inventory in the spent fuel pool (Ci)	
I-131	1.604E+4
I-132	1.307E+4
I-133	1.604E+3
– Initial pool water mass (lb)	1.4444E+6
– Fuel loading in the spent fuel pool	1 full core (150 hours decay)[(b)] 1/3 core (17 days decay) 10 years inventory of spent fuel
– Time delay to reach pool boiling (hr)	4.57
– Rate of evaporation at 4.57 hr (lb/min)	510
– Rate of evaporation at 30 days (lb/min)	284
– Iodine partition factor for water evaporating	100
– Water replacement to the pool	It is assumed that no water is added to the pool until the level drops to 8 feet above the stored fuel at 30 hours. Water is assumed to be added at a rate to maintain this level.

Note:

b. The fuel handling accident release of activity is based on the earliest possible fuel movement (100 hours after shutdown). The decay heat load is based on 150 hours to address the time required to perform a full core off-load. The inconsistency between the two times is a conservatism in the analysis.