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SOURCE TERMS RELEASED INTO THE ENVIRONMENT FOR A STATION BLACKOUT SEVERE ACCIDENT AT THE PEACH BOTTOM ATOMIC POWER STATION*

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DISCLAIMER

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ABSTRACT

This study calculates source terms released into the environment at the Peach Bottom Atomic Power Station after containment failure during a postulated low-pressure, short-term station blackout severe accident. The severe accident analysis code MELCOR[1], version 1.8.1, was used in these calculations. Source terms were calculated for three different containment failure modes. The largest environmental releases occur for early containment failure at the drywell liner in contact with the cavity by liner melt-through. This containment failure mode is very likely to occur when the cavity is dry during this postulated severe accident sequence.

1. INTRODUCTION

The Peach Bottom Atomic Power Station, Unit 2, is a BWR-4 reactor with a Mark-I containment. This containment comprises the drywell, which has the shape of an inverted light bulb, and the wetwell or suppression pool, which has the shape of a torus and is partially filled with water as shown in Fig. 1. The drywell is connected to the wetwell by eight vent lines. Steam produced in the drywell is vented into the wetwell and condensed in the water of the torus. Both drywell and wetwell are constructed of steel. The free volume of the drywell is 4,777 m^3 (169,500 ft^3) while the free volume of the wetwell is 3,170 m^3 (112,000 ft^3). The total volume of the wetwell (torus) is 7,132 m^3 (252,000 ft^3), with half of this volume occupied by water. The drywell and the wetwell compose the primary containment which is surrounded by the reactor building, also called the secondary containment. The secondary containment or reactor building, comprises five different floors. The bottom floor is the building basement where the wetwell torus is located. The top floor is the refueling bay.

The total power of the reactor is 3,293 MW(t) and the net electrical output is 1,065 MW(e) with a power density of 50.7 kW/L. Eleven Safety Relief Valves (SRVs) and two spring safety valves are connected to the steam lines of the reactor vessel . The Automatic Depressurization System (ADS) opens simultaneously five SRVs to depressurize the reactor vessel.

The severe accident analyzed, a low-pressure, short-term station blackout, assumes that all power is lost, except the batteries needed to actuate the SRVs and the ADS. None of the emergency core cooling systems (ECCS) is operational and the Reactor Core Isolation Cooling (RCIC) system is assumed to be failed also. Manual operation of the ADS is used to depressurize the reactor in conformance to Rev. 3 of the BWR Owners' Group Emergency Procedure Guidelines (EPGs)[2]. Revision 3 of the EPGs specifies that ADS actuation should be manually initiated when the water level in the core has fallen to about 1/3 of the active core height.

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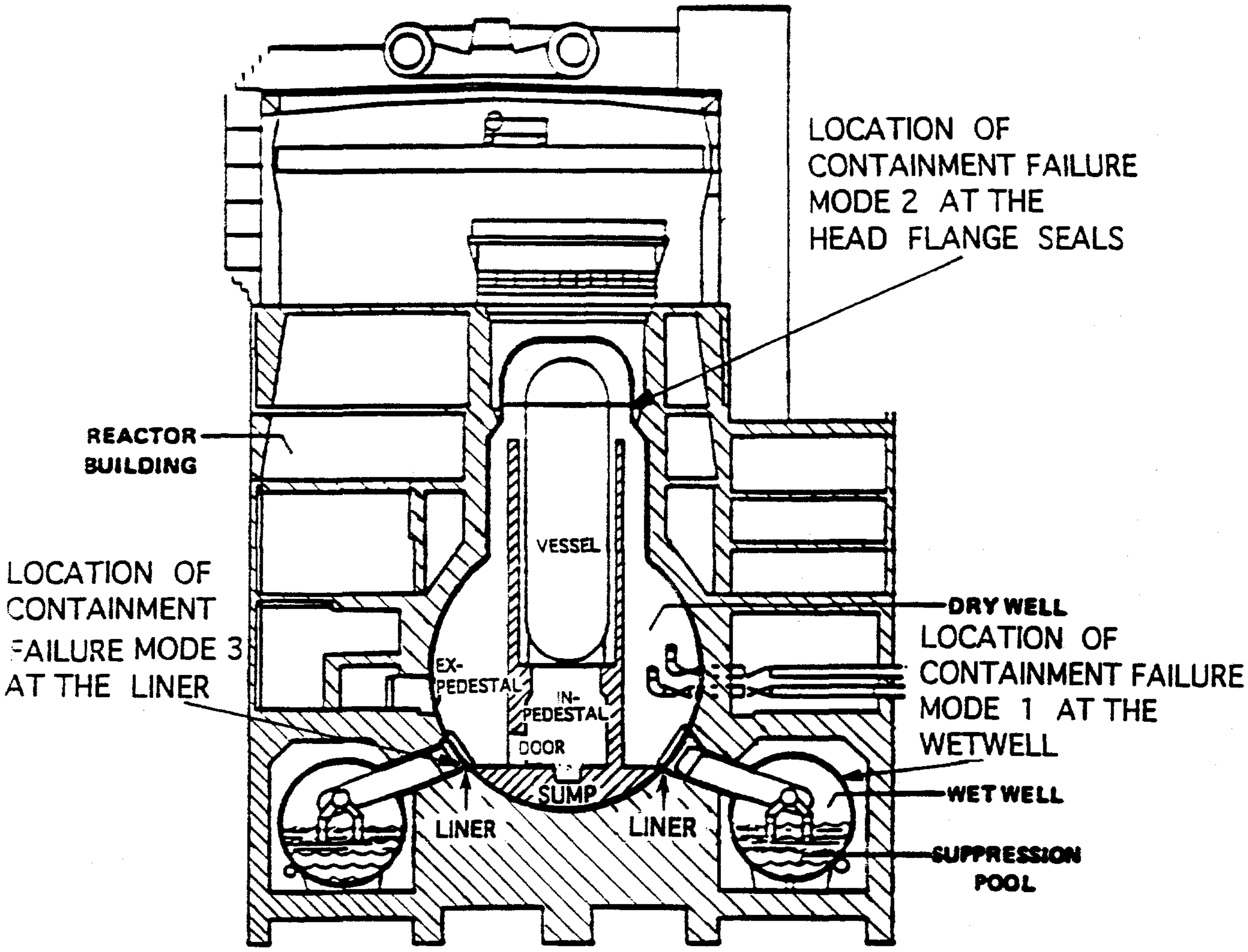

Fig.1 Peach Bottom Atomic Power Station with containment failure modes.

2. CONTAINMENT FAILURE MODES

There are three primary failure modes that have been identified[3-7] for Mark-I containments. These failure modes are: (1) high-pressure-induced primary containment failure, (2) high-temperature failure of the drywell head flange seals combined with a moderate drywell pressure, and (3) liner melt-through when hot debris in the cavity contacts the drywell liner. The locations of these containment failure modes are shown in Fig. 1.

These containment failure modes have been studied previously, and it has been determined[3,4] that containment failure mode 1 would occur at the upper region of the wetwell torus at a pressure of 1.2 MPa (159 psig), containment failure mode 2 would occur at the drywell head flange seals when the seals are degraded at a temperature above 644 K (700°F) combined with a pressure differential across the seals of 0.565 MPa (82 psig), and containment failure mode 3 would occur at the intersection of the drywell liner with the concrete floor of the cavity when the drywell liner melts (or creep ruptures) due to contact with hot molten core debris ejected after vessel failure. The melting temperature of the carbon steel liner is 1,810 K (2,800°F), and lower temperatures may induce creep rupture. For containment failure mode 2, the high temperature degrades the seals first, then the moderate pressure lifts the head from the drywell (Fig. 1) and leakage occurs. Once the seals are degraded by high temperature, leakage will occur if the pressure is above 0.565 MPa (82 psig) even if the temperature drops below the degrading temperature, since the damage to the seals is permanent.

The containment leakage area employed by MELCOR after containment failure is dependent on the failure mode. For containment failure modes 1 and 3, the assumed leakage area is 0.1 m^2 (1 ft^2), as estimated in Reference 5. For containment failure mode 2, according to Reference 6, the leakage area is pressure dependent, with zero leakage at a pressure differential across the seals of 0.565 MPa (82 psid) increasing to 0.04 m^2 (0.43 ft^2) at a pressure differential of 1.378 MPa (200 psid). Therefore, the higher the pressure differential, the larger the leakage area. This pressure-dependent failure area has the effect in code calculations of stabilizing the containment pressure, which typically remains slightly above the failure pressure, and results in small leakage areas and flows.

3. MELCOR MODEL

The severe accident code MELCOR,[1] version 1.8.1, was employed in these calculations. The MELCOR model of the Peach Bottom Atomic Power Station employs a total of 22 control volumes, six modeling the reactor vessel, 15 modeling the primary and secondary containment and one volume representing the environment. The primary containment is modeled with six control volumes: four for the drywell, one for the wetwell and one for the vent lines connecting the drywell and the wetwell. Figure 2 shows this MELCOR model of the plant. A total of 41 flowpaths connect these volumes. Each containment failure mode is modeled with a different flowpath. Flowpath 400 models containment failure mode 1. Flowpath 398 models containment failure mode 2. Flowpath 397 models containment failure mode 3.

In addition, 34 control functions, 30 tabular functions, and 73 heat slabs are employed in this MELCOR model. The core and lower plenum are nodalized with three radial rings and 11 axial levels. Five axial levels model the lower plenum, one models the core plate, and the remaining five levels model the core.

4. MELCOR RESULTS

Calculations[3,4] with the MELCOR code for a station blackout accident at the Peach Bottom plant with a *dry cavity* indicated that the containment would fail by ***liner melt-through*** (containment failure mode 3) shortly after vessel failure, in agreement with the results of Reference 7. If the *cavity is flooded*, liner melt-through would not occur and the containment would fail by high pressure in the *wetwell torus* (containment failure mode 1) about five hours after vessel failure. The best-estimate time calculated by MELCOR for vessel failure during this accident sequence was 285 min after accident initiation. The vessel failure time is the same for the three containment failure cases, since core melt progression and vessel failure is independent of the containment failure mode. The best-estimate time calculated for containment failure mode 1 was 617 min after accident initiation (332 min after vessel failure). Containment failure mode 3 was predicted by MELCOR if the following conditions occur simultaneously: (a) ten min have elapsed after vessel failure, (b) the cavity is dry, (c) more than 100,000 kg of molten core debris has been ejected into the cavity, and (d) the temperature of the debris in the cavity is over 1810 K, the melting temperature of steel. Conditions for liner melt-through are satisfied for this accident sequence with a dry cavity before other containment failure mode is predicted. Consequently, containment failure more 3 by liner melt-through was predicted to occur 10 min after vessel failure, or 295 min after accident initiation. The ten min time after vessel failure accounts for the time required for the hot debris to reach the liner and for the time needed to melt the liner.

Additional calculations indicated that containment failure mode 2 (at the drywell head flange seals) would occur at 548 min accident time (or 263 min after vessel failure). This time is almost as long as the containment failure time for failure mode 1. It appears, however, that containment failure mode 2 is unlikely to occur. This containment failure mode 2 was predicted by the MELCOR code with a dry cavity and with containment failure mode 3 deactivated. Otherwise, the conditions for containment failure mode 3 are satisfied first when the cavity is dry.

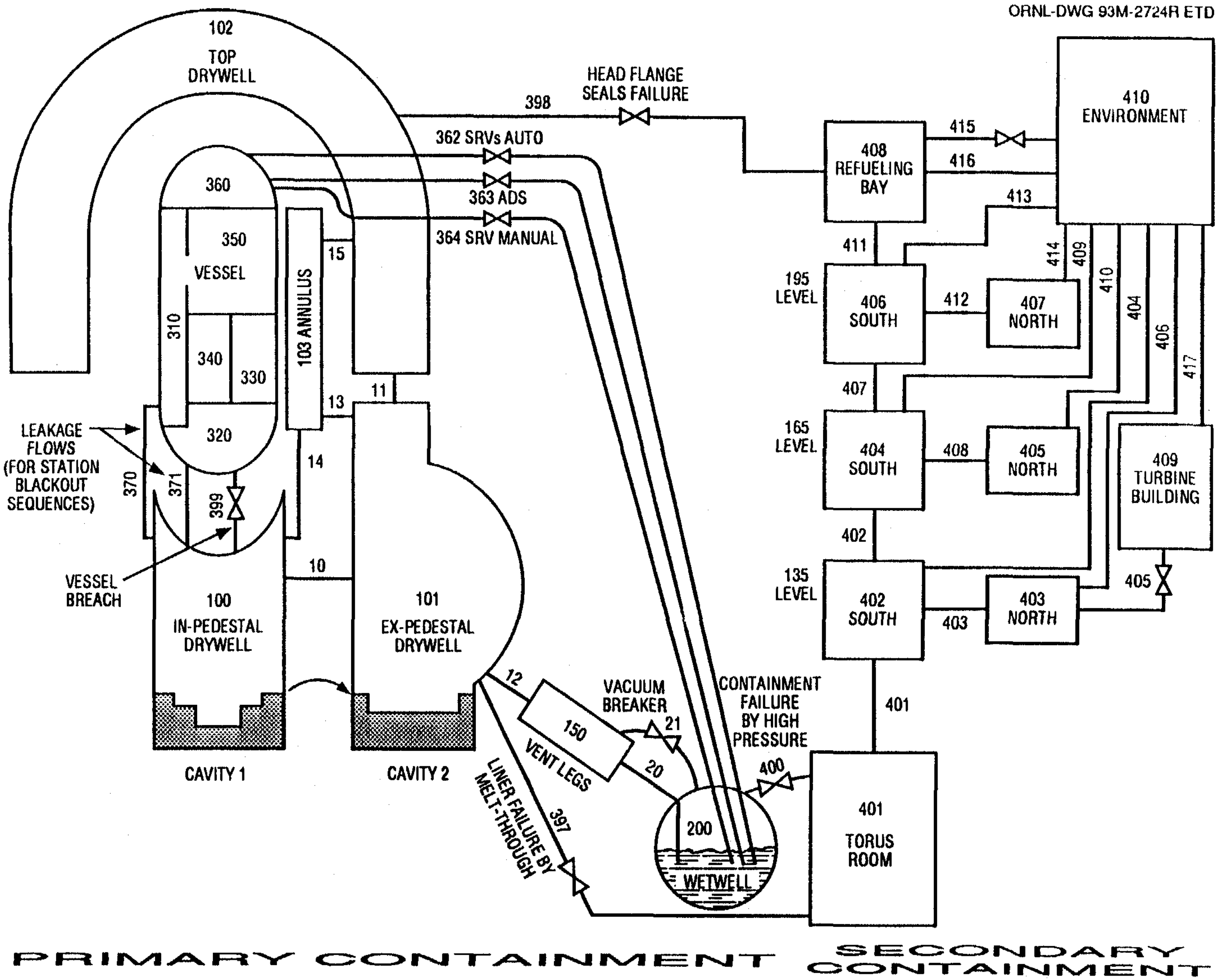

Fig.2 MELCOR model of the Peach Bottom Atomic Power Station.

Source terms released in-containment and into the environment were calculated for each of the three different containment failure modes. Table 1 presents the total in-containment source terms as a function of the containment failure mode. MELCOR calculates releases for 16 classes of fission products. Class 1 corresponds to the noble gases. No releases for class 4 (elemental iodine) are predicted because all iodine released is combined with released cesium from class 2 to form cesium iodide (CsI) into class 16. Class 13 corresponds to non-radioactive aerosols formed from the boron of the control rods. This model was deactivated in these calculations and, therefore, no boron aerosols were calculated. Class 14, water, is not used. Class 15 corresponds to non-radioactive aerosols formed from the cavity concrete during the core-concrete interaction. In these calculations, MELCOR employed the CORSOR fission product release model with the surface to volume ratio correction.

Table 1 shows that the total in-containment source terms are very similar for the three containment failure modes. The releases predicted for classes 2 (Cs), 3 (Ba, Sr), 5 (Te), and 16 (CsI) are larger for containment failure mode 3 (liner melt-trough) than for the other containment failure modes. This is because containment failure mode 3 resulted in the lowest containment pressure of the three containment failure modes and in the largest revaporization of fission products previously deposited inside the reactor vessel. The releases of all classes, except class 15, are given as fractions of the initial

Table 1. "Total" in-containment source terms calculated by MELCOR for the three containment failure modes at Peach Bottom

Containment failure mode		1 at the wetwell	2 at the head flange seals	3 at the drywell liner
Class	**Element**	**Fraction**	**Fraction**	**Fraction**
1	noble gases	0.9996	0.9487	0.9998
2	Cs	0.6396	0.6029	0.8139
3	Ba, Sr	0.2970	0.3878	0.4947
4	I	—	—	—
5	Te	0.2250	0.3563	0.5892
6	Ru	0.0021	0.0026	0.0025
7	Mo	0.0418	0.0509	0.0493
8	Ce	0	0.0010	0.0010
9	La	0.0129	0.0590	0.0479
10	U	0	0.0009	0.0009
11	Cd	0.1525	0.1944	0.2166
12	Sn	0.1565	0.2222	0.2166
13	B	---	---	---
14	H_2O	----	---	---
15	concrete	1,127 kg	933 kg	1,650 kg
16	CsI	0.6453	0.5927	0.7451

inventory of fission products. The releases of class 15 (concrete aerosols) are given in kg.

Table 2 presents the environmental fractional releases calculated for each of the 16 classes of MELCOR as a function of time after vessel failure and of containment failure mode. Figure 3 shows the environmental releases by class and containment failure mode at the end of the calculations (about 9 h after vessel failure). The largest and the earliest releases into the environment orrespond to the case when the containment ails early at the liner (mode 3). The smallest releases of noble gases are calculated for containment failure mode 2 at the drywell head flange seals. After the containment fails at the drywell head flange seals, the containment remains pressurized at a pressure differential slightly above 0.565 MPa (82 psid), the failure pressure for this containment failure mode. The leakage area is small, and only a small but continuous leakage of fission products takes place through the failed seals. Conversely, for containment failure mode 3 (liner melt-through), the leakage area is large (0.1 m^2), the containment is depressurized and, furthermore, the fission products bypass the pressure suppression pool, thereby losing its scrubbing benefits. The fractions of noble gases calculated to be released into the environment for containment failure mode 1 (wetwell failure by high pressure) are in between the fractions released for containment failure modes 2 and 3, but closer to the releases calculated for containment failure mode 3. Both containment failure modes 1 and 3 assume the same leakage area (0.1 m^2). For containment failure mode 1 the fission products go through the suppression pool and they are scrubbed in the pool water before they are released into the environment. Consequently, the fission product releases of classes 2 (Cs), 3 (Ba, Sr), 5 (Te) and 16 (CsI) are the smallest for containment failure mode 1.

5. CONCLUSIONS

In conclusion, the calculated fission products released into the environment after containment failure during a low-pressure, short-term station blackout severe accident at the Peach Bottom Atomic Power Station are strongly

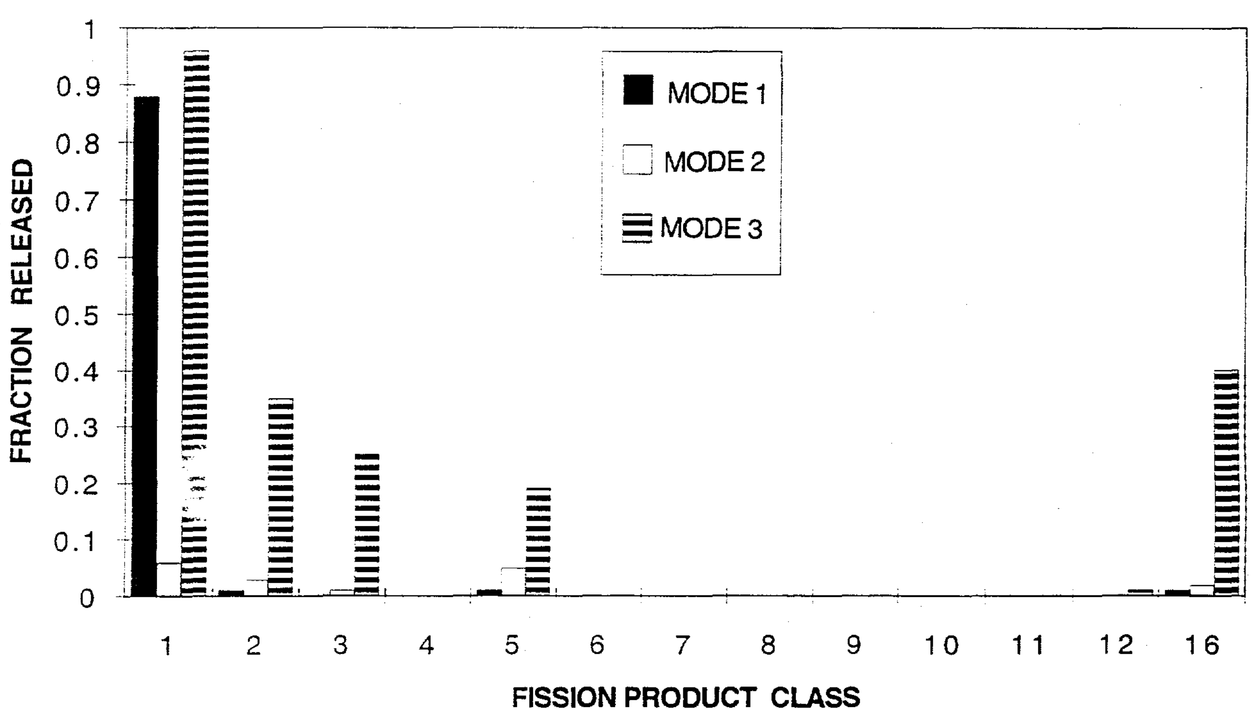

Fig. 3 Fractional releases into the environment as a function of fission product class and containment failure mode

Table 2. Fractional source terms released into the environment as a function of time and containment failure mode.

		Time after vessel failure, min (h)											
		60 (1)			300 (5)			360 (6)			556 (9.25)		
Class	Element	Mode 1	Mode 2	Mode 3	Mode 1	Mode 2	Mode 3	Mode 1	Mode 2	Mode 3	Mode 1	Mode 2	Mode 3
1	Noble gases	0	0	0.50	0	0.002	0.80	0.53	0.01	0.85	0.88	0.06	0.96
2	Cs	0	0	0.10	0	0.001	0.16	0.004	0.02	0.20	0.01	0.03	0.35
3	Ba, Sr	0	0	0.05	0	0.003	0.08	10^{-4}	0.005	0.10	0.001	0.01	0.25
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5	Te	0	0	0.05	0	0.01	0.10	0.003	0.02	0.15	0.01	0.05	0.19
6	Ru	0	0	10^{-4}	0	10^{-9}	10^{-3}	10^{-6}	10^{-8}	10^{-3}	10^{-6}	10^{-7}	10^{-3}
7	Mo	0	0	10^{-4}	0	10^{-5}	10^{-3}	10^{-4}	10^{-5}	10^{-3}	10^{-4}	10^{-5}	10^{-3}
8	Ce	0	0	10^{-4}	0	10^{-8}	10^{-3}	10^{-7}	10^{-6}	10^{-3}	10^{-6}	10^{-6}	10^{-3}
9	La	0	0	10^{-5}	0	10^{-6}	10^{-3}	10^{-5}	10^{-4}	10^{-3}	10^{-5}	10^{-4}	10^{-3}
10	U	0	0	10^{-5}	0	10^{-7}	10^{-4}	10^{-7}	10^{-6}	10^{-4}	10^{-6}	10^{-6}	10^{-4}
11	Cd	0	0	10^{-4}	0	10^{-6}	10^{-3}	10^{-4}	10^{-4}	10^{-3}	10^{-4}	10^{-4}	10^{-3}
12	Sn	0	0	10^{-4}	0	10^{-6}	0.01	10^{-4}	10^{-4}	0.02	10^{-4}	10^{-3}	0.04
16	CsI	0	0	0.10	0	0.001	0.20	0.003	0.006	0.26	0.01	0.02	0.40

Containment failure **modes** and **times** of occurrence after vessel failure:

Mode 1. Wetwell failure by high pressure (1.2 MPa or 159 psig) at 332 min.

Mode 2. Drywell head flange seals failure by high temperature (644 K) and moderate pressure (0.565 MPa or 82 psid) at 263 min.

Mode 3. Drywell liner melt-through by contact with hot debris at a temperature above 1,810 K at 10 min.

dependent on the containment failure mode. Three containment failure modes have been identified and have been implemented into the MELCOR model of the plant. The *largest releases* have been calculated to occur when the containment fails at the drywell liner by *liner melt-through* (containment failure mode 3), a very likely failure mode when the cavity is dry. The smallest releases of noble gases are predicted when the containment fails at the drywell head flange seals by temperature degradation, a very unlikely failure mode. If the cavity is flooded, the most likely containment failure mode is by high pressure at the wetwell torus (containment failure mode 1). Since the largest source term releases are predicted for containment failure mode 3 (drywell liner melt-through), this failure mode should be prevented from occurring. Cavity flooding will prevent drywell liner melt-through.

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