Appendix A: Releases from Containment

The following is an excerpt from Appendix VI, Section 2 of WASH-1400 (NUREG-75/104), "Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants," dated October 1975.

On this page:

A large portion of the work of the Reactor Safety Study was expended in determining the probability and magnitude of various radioactive releases. This work is described in detail in the preceding appendices as well as Appendices VII and VIII. In order to define the various releases that might occur, a series of release categories were identified for the postulated types of containment failure in both BWRs and PWRS. The probability of each release category and the associated magnitude of radioactive releases (as fractions of the initial core radioactivity that might leak from the containment structure) are used as input data to the consequence model.

In addition to probability and release magnitude, the parameters that characterize the various hypothetical accident sequences are time of release, duration of release, warning time for evacuation, height of release, and energy content of the released plume.

The time of release refers to the time interval between the start of the hypothetical accident and the release of radioactive material from the containment building to the atmosphere; it is used to calculate the initial decay of radioactivity. The duration of release is the total time during which radioactive material is emitted into the atmosphere; it is used to account for continuous releases by adjusting for horizontal dispersion due to wind

meander. These parameters, time and duration of release, represent the temporal behavior of the release in the dispersion model. They are used to model a "puff" release from the calculations of release versus time presented in Appendix V.

The warning time for evacuation (see Section 1.1.1) is the interval between awareness of impending core melt and the release of radioactive material from the containment building. Finally, the height of release and the energy content of the released plume gas affect the manner in which they would be dispersed in the atmosphere.

Table VI 2-1 lists the leakage parameters that characterize the PWR and BWR release categories. It should be understood that these categories are composites of numerous event tree sequences with similar characteristics, as discussed in Appendix V.

To help the reader understand the postulated containment releases, this section presents brief descriptions of the various physical processes that define each release category. For more detailed information on the release categories and the techniques employed to compute the radioactive releases to the atmosphere, the reader is referred to Appendices V, VII, and VIII. The dominant event tree sequences in each release category are discussed in detail in Section 4.6 of Appendix V.

This release category can be characterized by a core meltdown followed by a steam explosion on contact of molten fuel with the residual water in the reactor vessel. The containment spray and heat removal systems are also assumed to have failed and, therefore, the containment could be at a pressure above ambient at the time of the steam explosion. It is assumed that the steam explosion would rupture the upper portion of the reactor vessel and breach the containment barrier, with the result that a substantial amount of radioactivity might be released from the containment in a puff over a period of about 10 minutes. Due to the sweeping action of gases generated during containment-vessel melt-through, the release of radioactive materials would continue at a relatively low rate thereafter. The total release would contain approximately 70% of the iodines and 40% of the alkali metals present in the core at the time of release.[1] Because the containment would contain hot pressurized gases at the time of failure, a relatively high release rate of sensible energy from the containment could be associated with this category. This category also includes certain potential accident sequences that would involve the occurrence of core melting and a steam explosion after containment rupture due to overpressure. In these sequences, the rate of energy release would be lower, although still relatively high.

The release fractions of all the chemical species are listed in Table VI 2-1. The release fractions of iodine and alkali metals are indicated here to illustrate the variations in release with release category.

This category is associated with the failure of core-cooling systems and core melting concurrent with the failure of containment spray and heat-removal systems. Failure of the containment barrier would occur through overpressure, causing a substantial fraction of the containment atmosphere to be released in a puff over a period of about 30 minutes. Due to the sweeping action of gases generated during containment vessel melt- through, the release of radioactive material would continue at a relatively low rate thereafter. The total release would contain approximately 70% of the iodines and 50% of the alkali metals present in the core at the time of release. As in PWR release category 1, the high temperature and pressure within containment at the time of containment failure would result in a relatively high release rate of sensible energy from the containment.

This category involves an overpressure failure of the containment due to failure of containment heat removal. Containment failure would occur before the commencement of core melting. Core melting then would cause radioactive materials to be released through a ruptured containment barrier. Approximately 20% of the iodines and 20% of the alkali metals present in the core at the time of release would be released to the atmosphere. Most of the release would occur over a period of about 1.5 hours. The release of radioactive material from containment would be caused by the sweeping action of gases generated by the reaction of the molten fuel with concrete. Since these gases would be initially heated by contact with the melt, the rate of sensible energy release to the atmosphere would be moderately high.

This category involves failure of the core-cooling system and the containment spray injection system after a loss-of-coolant accident, together with a concurrent failure of the containment system to properly isolate. This would result in the release of 9% of the iodines and 4% of the alkali metals present in the core at the time of release. Most of the release would occur continuously over a period of 2 to 3 hours. Because the containment recirculation spray and heat-removal systems would operate to remove heat from the containment atmosphere during core melting, a relatively low rate of release of sensible energy would be associated with this category.

This category involves failure of the core cooling systems and is similar to PWR release category 4, except that the containment spray injection system would operate to further reduce the quantity of airborne radioactive material and to initially suppress containment temperature and pressure. The containment barrier would have a large leakage rate due to a concurrent failure of the containment system to properly isolate, and most of the radioactive material would be released continuously over a period of several hours. Approximately 3% of the iodines and 0.9% of the alkali metals present in the core would be released. Because of the operation of the containment heat-removal systems, the energy release rate would be low.

This category involves a core meltdown due to failure in the core cooling systems. The containment sprays would not operate, but the containment barrier would retain its integrity until the molten core proceeded to melt- through the concrete containment base mat. The radioactive materials would be released into the ground, with some leakage to the atmosphere occurring upward through the ground. Direct leakage to the atmosphere would also occur at a low rate before containment-vessel melt-through. Most of the release would occur continuously over a period of about 10 hours. The release would include approximately 0.08% of the iodines and alkali metals present in the core at the time of release. Because leakage from containment to the atmosphere would be low and gases escaping through the ground would be cooled by contact with the soil, the energy release rate would be very low.

This category is similar to PWR release category 6, except that containment sprays would operate to reduce the containment temperature and pressure as well as the amount of airborne radioactivity. The release would involve 0.002% of the iodines and 0.001% of the alkali metals present in the core at the time of release. Most of

the release would occur over a period of 10 hours. As in PWR release category 6, the energy release rate would be very low.

This category approximates a PWR design basis accident (large pipe break), except that the containment would fail to isolate properly on demand. The other engineered safeguards are assumed to function properly. The core would not melt. The release would involve approximately 0.01% of the iodines and 0.05% of the alkali metals.

Most of the release would occur in the 30-minute period during which containment pressure would be above ambient. Because containment sprays would operate and core melting would not occur, the energy release rate would also be low.

This category approximates a PWR design basis accident (large pipe break), in which only the activity initially contained within the gap between the fuel pellet and cladding would be released into the containment. The core would not melt. It is assumed that the minimum required engineered safeguards would function satisfactorily to remove heat from the core and containment. The release would occur over the 30-minute period during which the containment pressure would be above ambient. Approximately 0.00001% of the iodines and 0.00006% of the alkali metals would be released. As in PWR release category 8, the energy release rate would be very low.

This release category is representative of a core meltdown followed by a steam explosion in the reactor vessel. The latter would cause the release of a substantial quantity of radioactive material to the atmosphere The total release would contain approximately 40% of the iodines and alkali metals present in the core at the time of containment failure. Most of the release would occur over a 30-minute period. Because of the energy generated in the steam explosion, this category would be characterized by a relatively high rate of energy release to the atmosphere. This category also includes certain sequences that involve overpressure failure of the containment before core melting and a steam explosion. In these sequences, the rate of energy release would be somewhat smaller than for those discussed above, although it would still be relatively high.

This release category is representative of a core meltdown resulting from a transient event in which decay-heat- removal systems are assumed to fail. Containment overpressure failure would result, and core melting would follow. Most of the release would occur over a period of about 3 hours. The containment failure would be such that radioactivity would be released directly to the atmosphere without significant retention of fission products.

This category involves a relatively high rate of energy release due to the sweeping action of the gases generated by the molten mass. Approximately 90% of the iodines and 50% of the alkali metals present in the core would be released to the atmosphere.

This release category represents a core meltdown caused by a transient event accompanied by a failure to scram or failure to remove decay heat. Containment failure would occur either before core melt or as a result of gases generated during the interaction of the molten fuel with concrete after reactor-vessel melt-through.

Some fission-product retention would occur either in the suppression pool or the reactor building before release to the atmosphere. Most of the release would occur over a period of about 3 hours and would involve 10%

of the iodines and 10% of the alkali metals. For those sequences in which the containment would fail due to overpressure after core melt, the rate of energy release to the atmosphere would be relatively high. For those sequences in which overpressure failure would occur before core melt, the energy release rate would be somewhat smaller, although still moderately high.

This release category is representative of a core meltdown with enough containment leakage to the reactor building to prevent containment failure by overpressure. The quantity of radioactivity released to the atmosphere

Releas Btu/hr) (hr)	Probability	Fraction of Core	Catego yr)$^{-1}$	Time of (reactor- Inventory		Duration Release (hr) Released[a]		Warning of Release	Elevati	Time forof (hr)		Energy Release Evacuation	Release	(10^6 (m
	Xe- Xr	Organic I[b]			I[b]	Cs-Rb		Te-Sb		Ba-Sr		Ru[c]		La[d]
PWR 1	9×10^{-7}[e]	2.5	0.5	1.0	25	25 and 520[e]	0.9	6×10^{-3}	0.7	0.4	0.4	0.05	0.4	3×10^{-3}
PWR 2	8×10^{-6}	2.5	0.5	1.0	0	170	0.9	7×10^{-3}	0.7	0.5	0.3	0.06	0.02	4×10^{-3}
PWR 3	4×10^{-6}	5.0	1.5	2.0	0	6	0.8	6×10^{-3}	0.2	0.2	0.3	0.02	0.03	3×10^{-3}
PWR 4	5×10^{-7}	2.0	3.0	2.0	0	1	0.6	2×10^{-3}	0.09	0.04	0.03	5×10^{-3}	3×10^{-3}	4×10^{-4}
PWR 5	7×10^{-7}	2.0	4.0	1.0	0	0.3	0.3	2×10^{-3}	0.03	9×10^{-3}	5×10^{-3}	1×10^{-3}	6×10^{-4}	7×10^{-5}
PWR 6	6×10^{-6}	12.0	10.0	1.0	0	N/A	0.3	2×10^{-3}	8×10^{-4}	8×10^{-4}	1×10^{-3}	9×10^{-5}	7×10^{-5}	1×10^{-5}
PWR 7	4×10^{-5}	10.0	10.0	1.0	0	N/A	6×10^{-3}	2×10^{-5}	2×10^{-5}	1×10^{-5}	2×10^{-5}	1×10^{-6}	1×10^{-6}	2×10^{-7}
PWR 8	4×10^{-5}	0.5	0.5	N/A[f]	0	N/A	2×10^{-3}	5×10^{-6}	1×10^{-4}	5×10^{-4}	1×10^{-6}	1×10^{-8}	0	0
PWR 9	4×10^{-4}	0.5	0.5	N/A	0	N/A	3×10^{-6}	7×10^{-9}	1×10^{-7}	6×10^{-7}	1×10^{-9}	1×10^{-11}	0	0
BWR 1	1×10^{-6}	2.0	0.5	1.5	25	130	1.0	7×10^{-3}	0.40	0.40	0.70	0.05	0.5	5×10^{-3}
BWR 2	6×10^{-6}	30.0	3.0	2.0	0	30	1.0	7×10^{-3}	0.90	0.50	0.30	0.10	0.03	4×10^{-3}

BWR 3	2 x 10^{-5}	30.0	3.0	2.0	25	20	1.0	7 x 10^{-3}	0.10	0.10	0.30	0.01	0.02	4 x 10^{-3}
BWR 4	2 x 10^{-6}	5.0	2.0	2.0	25	N/A	0.6	7 x 10^{-4}	8 x 10^{-4}	5 x 10^{-3}	4 x 10^{-4}	6 x 10^{-4}	6 x 10^{-4}	1 x10^{-4}

would be significantly reduced by normal ventilation paths in the reactor building and potential mitigation by the secondary containment filter systems. Condensation in the containment and the action of the standby gas

treatment system on the releases would also lead to a low rate of energy release. The radioactive material would be released from the reactor building or the stack at an elevated level. Most of the release would occur over a 2- hour period and would involve approximately 0.08% of the iodines and 0.5% of the alkali metals.

This category approximates a BWR design basis accident (large pipe break) in which only the activity initially contained within the gap between the fuel pellet and cladding would be released into containment. The core would not melt, and containment leakage would be small. It is assumed that the minimum required engineered safeguards would function satisfactorily. The release would be filtered and pass through the elevated stack. It would occur over a period of about 5 hours while the -9 containment is pressurized above ambient and would involve approximately 6 x 10% of the iodines and 4 x 10% of the alkali metals. Since core melt would not occur and containment heat-removal systems would operate, the release to the atmosphere would involve a negligibly small amount of thermal energy.

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Releas Btu/hr) (hr)	Probability	Fraction Catego	of Core yr)$^{-1}$		Time of (reactor- Inventory	Duration Release (hr) Released(a)		Warning of Release		Elevati Time forof (hr)	Energy Release	Evacua Release(m		(10^{6}
Xe- Xr		Organic I(b)			I(b)	Cs-Rb		Te-Sb		Ba-Sr		Ru(c)		La(d)
BWR 5	1 x 10^{-4}	3.5	5.0	N/A	150	N/A	5 x 10^{-4}	2 x 10^{-9}	6 x 10^{-11}	4 x 10^{-9}	8 x 10^{-14}	8 x 10^{-14}	0	0

(A) Background on the isotope groups and release mechanisms is presented in Appendix VII.

(a) Organic iodine is combined with elemental iodines in the calculations. Any error is negligible since its release fraction is relatively small for all large release categories.

(b) Includes Ru, Rh, Co, Mi, Tc.

(D) Includes Y, La, Zr, Nb, Ce, Pr, Nd, Np, Pu, AM, CM.

(E) Accident sequences within PWR 1 category have two distinct energy releases that effect consequences. PWR 1 category is subdivided into PWR 1a with a probability of 4 x 10^{-7} per reactor-year and 20 x 10^{6} Btu/hr and PWR 1b with a probability of 5 x 10^{-7} per reactor year and 520 x 10^{6} Btu/hr.

(f) Not applicable.

(g) A 10 meter elevation is used in place of zero representing the mid-point of a potential containment break. Any impact on the results would be slight and conservative.