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Uncertainty of Leak Path Fraction in Source Term Assessment of Fuel Examination Facility

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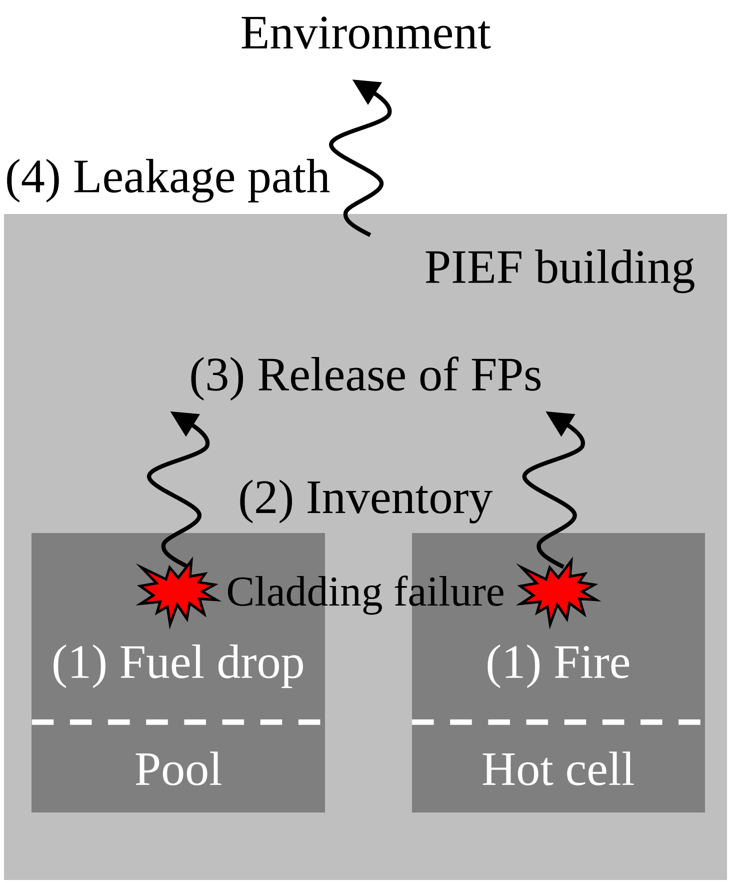
Source term assessment

Accident analysis of Post Irradiation Examination Facility*
(PIEF in the KAERI site)



(1) Failure scenario of spent fuel in pool and a hot cell
(2) Initial inventory of radionuclides within the failed fuel
(3) Release fraction of the fission products from cladding failure
(4) Leak path fraction of aerosol and vapor releasing into the environment

Different from source term assessment of a general nuclear power plant under a SA

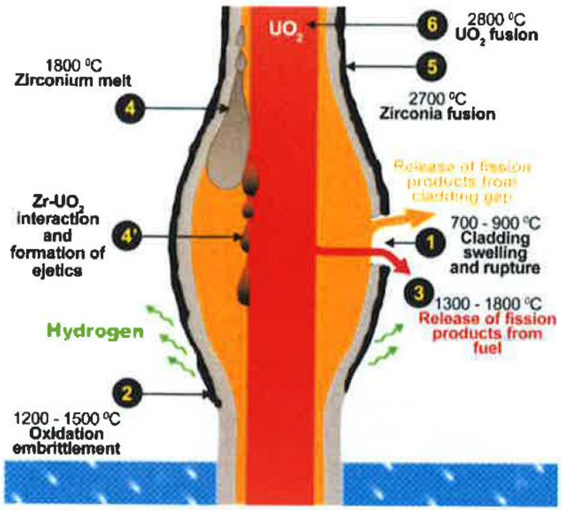
I. Relatively **low decay heat** of spent fuel,

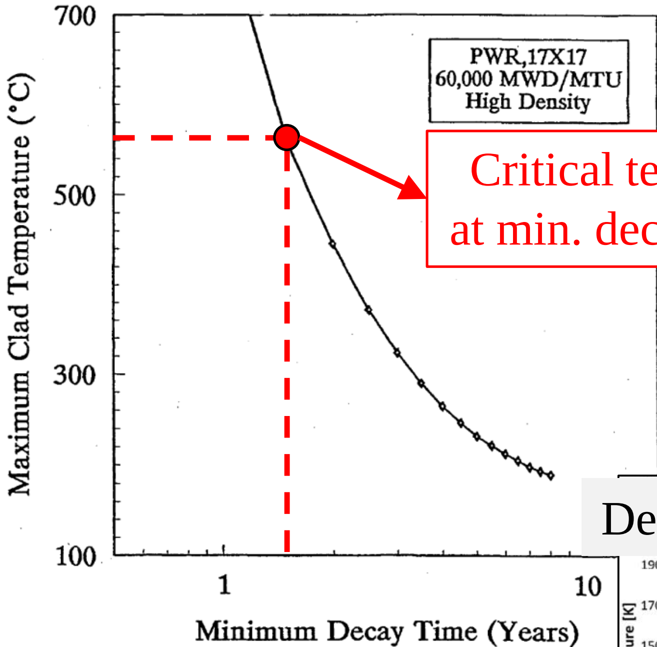
II. Atmosphere composed mostly of **air** in PIEF

*KAERI/TR-7594/2019, KAERI/TR-6394/2016

(1) Failure scenario

Fuel cladding failure[1]



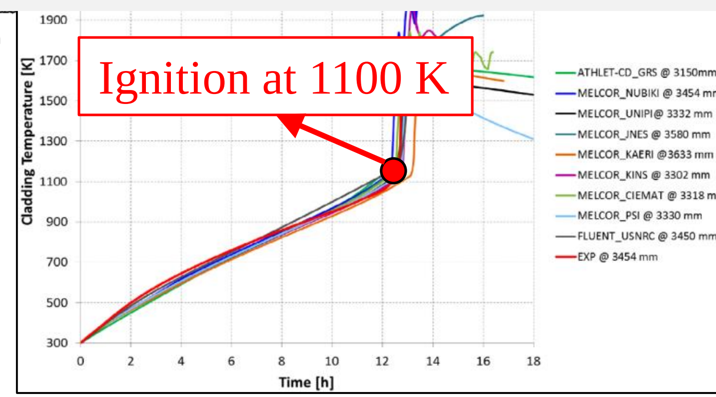


Minimum decay time[2]

Critical temperature(565 ℃)
at min. decay time(17 months)

→ Cladding oxidation will not occur for the spent fuel cooled for more than 17 months

Decay power at 17 months = 5 kW[3]



Zr exothermic oxidation(steam vs. air)

$$Zr + 2H_2O \rightarrow ZrO_2 + 2H_2 + 5.8 \cdot 10^6 \mathrm{J/kg}$$

$$Zr + O_2 \rightarrow ZrO_2 + \mathbf{1.2 \cdot 10^7 J/kg}$$

Uncertainty of air cooling of spent fuels[4]

(1) Heat Transfer Engineering, 36(2015), Hydrogen Distribution in Nuclear Reactor Containment During Accidents and Associated Heat and Mass Transfer Issues-A Review
(2) NUREG/CR-6451(1997), A Safety and Regulatory Assessment of Generic BWR and PWR Permanently Shutdown Nuclear Power Plants, (3) NED, 307(2016), OECD/NEA Sandia Fuel Project phase I: Benchmark of the ignition testing
(4) IAEA-TECDOC-1949(2021), Phenomenology, Simulation and Modelling of Accidents in Spent Fuel Pools

(2) Initial inventory

Inventory = *f* (burnup, cooling period)

Inventory(60 GWD/tU, OPR PLUS7) calculated by ORIGEN code*

Nuclide		Inventory(Ci/one rod) after decay(Cooling)					
		0.5YR	1.5YR	2.5YR	3.5YR	10.0YR	25.0YR
NG	KR85	28.6	26.8	25.1	23.6	15.5	5.87
CS	CS134	591	422	302	216	24.3	0.157
	CS137	333	325	318	311	267	189
TE	TE127	9.16	0.898	0.0881	0.00863	2.40E-09	1.78E-24
	TE127M	9.36	0.917	0.0899	0.00881	2.45E-09	1.81E-24
	TE129	1.33	0.00071	3.79E-07	2.03E-10	1.09E-31	0

e.g. Inventory(60 GWD/tU, OPR PLUS7) of 1699 fuels cooled down for 1.5 YR

Group	Nuclide	Inventory		
		Ci/one rod	Total # of rod	MAR(Ci)
NG	KR85	26.8	1699	4.55E+04
CS	CS134	422	1699	7.17E+05
	CS137	325	1699	5.52E+05
TE	TE127	0.898	1699	1.53E+03
	TE127M	0.917	1699	1.56E+03
	TE129	0.00071	1699	1.21E+00

→ Convert into mass in code calculation

Nuclide	원자량 (g/mol)	반감기 (sec)	붕괴상수 (1/sec)	방사능양		질량 (g)
				(Ci)	(Bq)	
KR85	85	3.39E+08	2.04E-09	4.55E+04	1.6847E+15	116.31

*KAERI/TR-7594/2019, KAERI/TR-6394/2016

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(3) Release fraction

Release fraction of FPs = *f* (failure scenario*)

Fuel cladding failed by **drop**** in a pool or **fire** in a hot cell

Mechanical failure of fuel in a pool
→ Assume as a Cold-gap

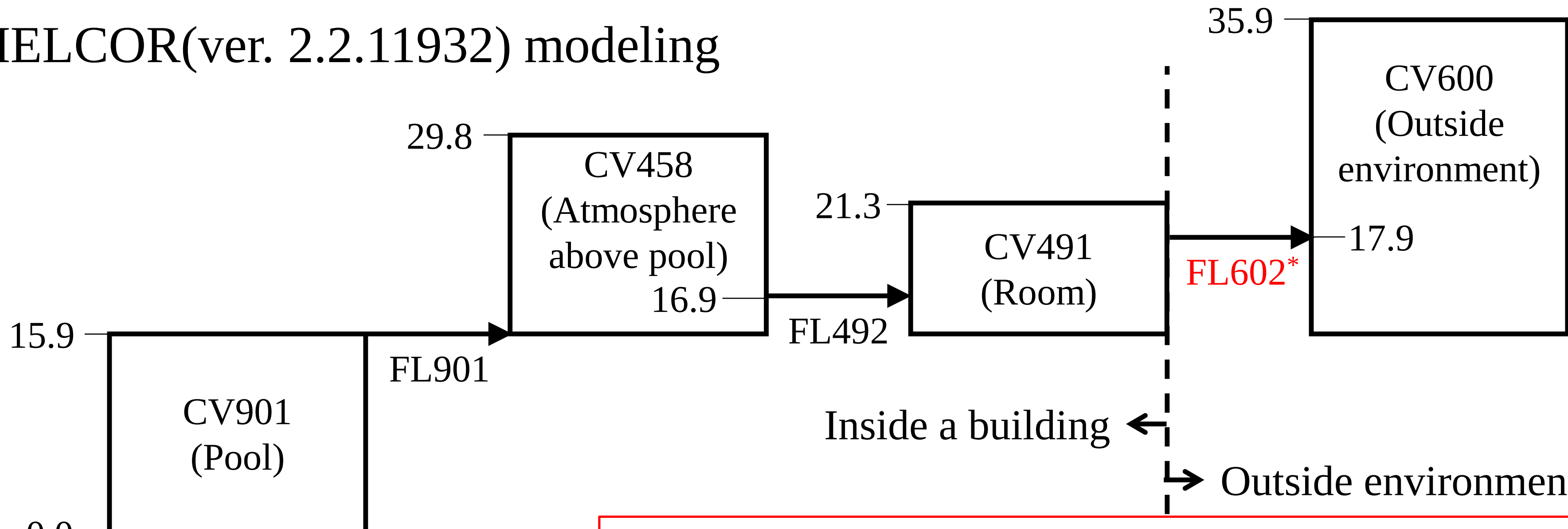
Key nuclide	Type	Accident scenario		
		Hot-gap	Cold-gap	Fire
KR85	Gas	0.4	0.4	1
CS134	Aerosol	0.03	0.003	0.3
CS137		0.03	0.003	0.3
TE127		0.001	0.0001	0.006
TE127M		0.001	0.0001	0.006
TE129		0.001	0.0001	0.006

Effect of pool scrubbing

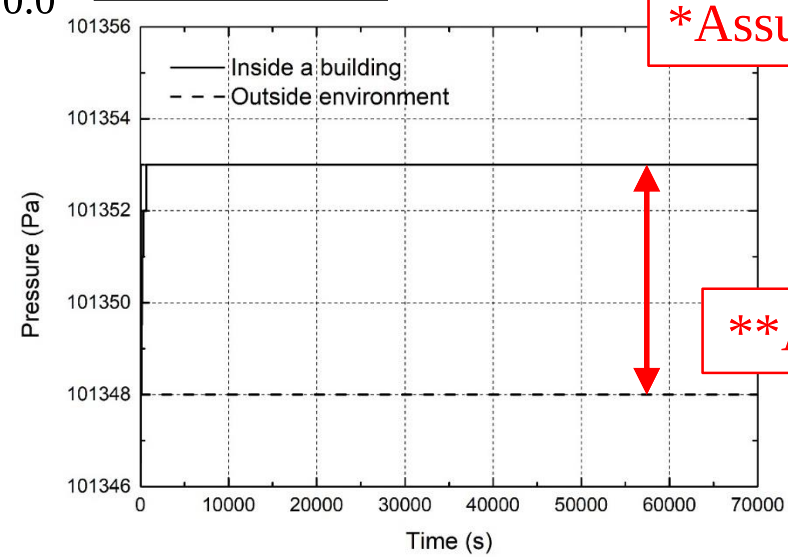
*NUREG/CR-6451(1997), **Impossible to simulate a falling accident using a accident analysis code

(4) Leak path fraction

MELCOR(ver. 2.2.11932) modeling



*Assume as leak path(FL602) diameter(0.00635 m)



Pressure difference** caused by wind blowing on the exterior wall of PIEF

**Assumed to be 5.25 Pa at wind speed of 5 m/s

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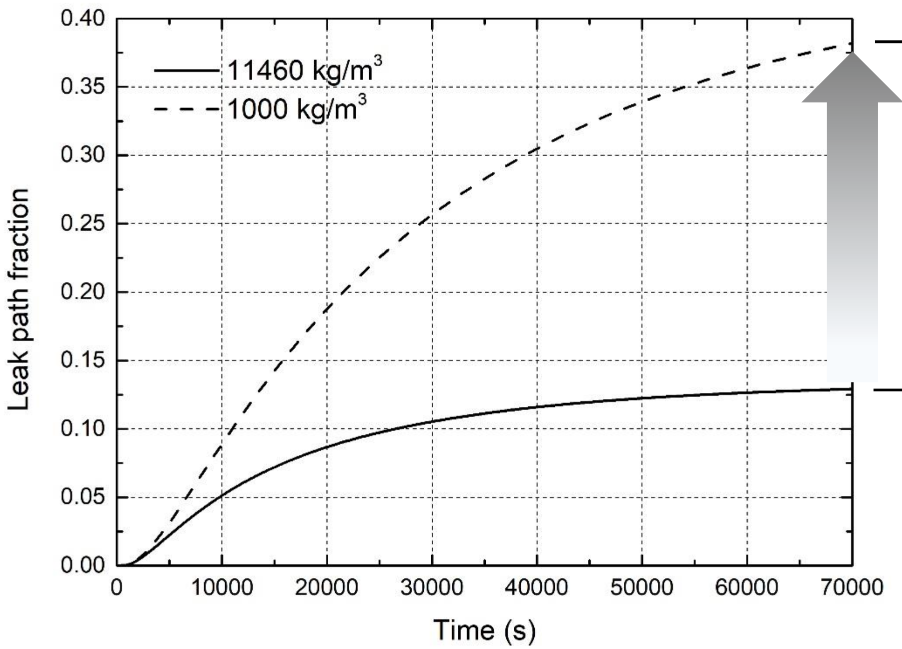
(4) Leak path fraction



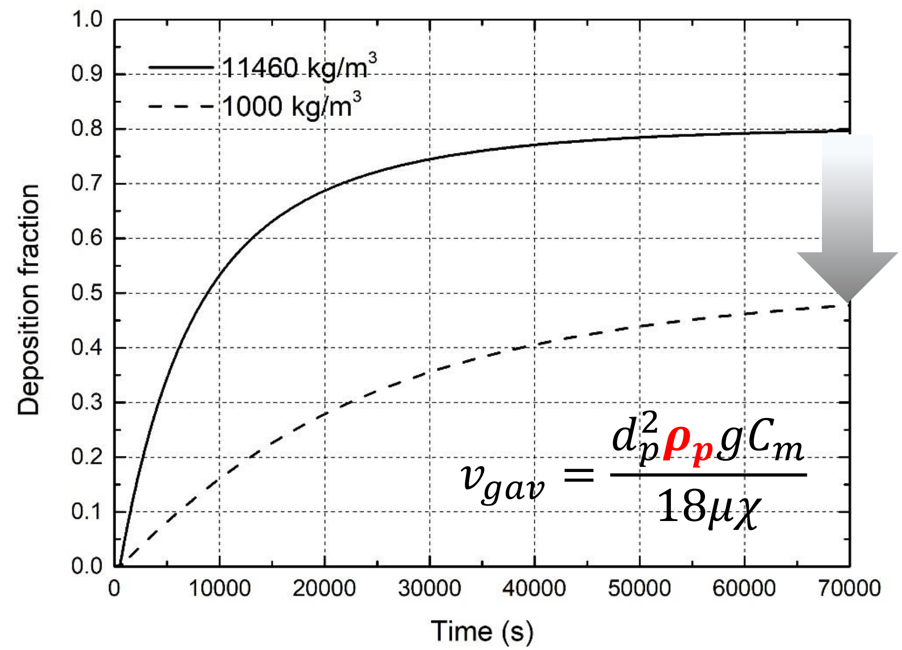
→ Aerosol density[2] 1,000 kg/m^3

Leak path fraction of aerosol increased from 0.13 to 0.38

→ Aerosol density[1] 11,460 kg/m^3

Aerosol deposition on a building by gravitational settling(v_{gav})

Uncertainty of effective density of aerosol particle[3] in air



$$v_{gav} = \frac{d_p^2 \boldsymbol{\rho_p} g C_m}{18\mu\chi}$$

(1) KAERI/TR-6394/2016, (2) default(the atmosphere filled with steam) in MELCOR, (3) CS(1,930 kg/m^3), TE(6,240 kg/m^3)

Conclusion

Uncertainty of Source term(ST*) = (3) MAR x (5) ARF x (6) LPF

Nuclide	Inventory			Release fraction			ST
	Ci/one rod	Total # of rod	MAR(Ci)	(4) Scenario	(5) ARF	(6) LPF	(Ci)
Kr	(1)	(2)	(3) = (1) x (2)	cold-gap	0.4	0.7	(3) x (5) x (6)
Cs					0.003	0.13	
Te					0.0001	0.13	

(3) MAR(Material-At-Risk): Krypton(Kr), cesium(Cs), and tellurium(Te) were chosen as the main radionuclides in source term assessment of PIEF. Their inventory depends on burnup and cooling period. **(4)** We did not consider a drainage scenario that can expose fuel in air. Fuel failure induced by cladding oxidation will not occur for the spent fuel cooled for more than 17 months, because of the low decay heat. **(5) ARF**(Airborne Release Fraction): Release fractions of key radionuclides were set, because it is impossible to simulate a falling accident using a MELCOR code. A cold-gap presents mechanical failure of spent fuel in a storage pool. The release fraction of a cold-gap is one tenth of that of a hot-gap that indicates an accident of spent fuel cladding failed by exothermic oxidation. It was assumed that 90% of aerosol could be removed by pool scrubbing. **(6) LPF**(Leak Path Fraction) can strongly depend on the aerosol density that is one of the key uncertainty factors. It is important to decide the effective density of aerosol particles suspended in air, because gravitational settling determined by the particle density will be dominated to particle deposition in a large scaled building.

*KAERI/TR-7594/2019