IAEA-CN-214-26

IAEA
International Atomic Energy Agency
International Conference on Challenges Faced by Technical and Scientific Support Organizations (TSOs) in Enhancing Nuclear Safety and Security
27-31 October 2014, Beijing, China

Application of RASCAL 4.2 to estimate the Fukushima Accident Source Term

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1. Introduction and Methods

This poster presents the results of the application of the fast-running US-NRC direct code **RASCAL 4.2** to the estimation of the **Fukushima Accident Source Term (ST)**.

The RASCAL 4.2 module, sub-modules and related parameters used are presented in Tab. 1. The possible dominant release paths are show in Fig. 1.

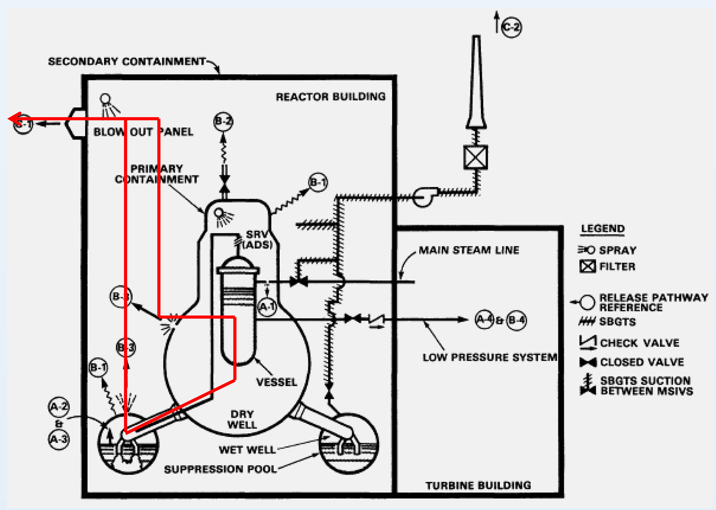

Figure 1: BWR Mark I - Possible release pathways

Module	
Source Term to Dose	
Sub-Module	**Parameter**
Event Type	NPP
Event Location	Cooper, Duane Arnold
Source Term	Time core is uncovered
Release Path	Drywell + Direct

Table 1: RASCAL 4.2 parameters

2. Hypothesis of accident sequence

The choice of the release path has been made on the base of a comparison between the ST estimates already available and a calculation of I-131 and Cs-137 for four combinations of possible release pathways.

Direct Code	Release path					Emission [Bq]	
RASCAL 4.2	Wetwell	Drywell	Bypass	SGTS	Direct	I-131	Cs-137
	x			x		3.2E11	3.9E10
	x				x	3.2E13	3.9E12
		x			x	3.2E15	3.9E14
			x			1.4E18	1.5E17
Comparison value	–					1.3E17	1.1E16

} too low (first two rows)

} too high (last row)

Table 2: Selection of a release pathway

Table 2 shows that <u>the most probable path is the combination of ***Drywell (D/W) + Direct*** option</u>. The average values chosen for design and accident parameters are:

- Nominal leakage from reactor building (RB): **0.5%/d**;
- Leakage from RB at the beginning of core damage: **1%/h**;
- Ventings: **25%/h for 1 hour**;
- Explosions: **50%/h for 1 hour**.

Unit 1: Sequence and Modeling

Date	Fukushima Local Time	Event	ΔT since SCRAM [h]	ENEA Hypotheses
11/03/11	14:46:00	SCRAM		
11/03/11	17:16:00	Core uncovery	2.50	Core uncovery
12/03/11	14:30:00	Start venting, disk rupture	23.73	Drywell venting
12/03/11	15:36:00	Explosion	24.83	

Unit 1 had no core-recovery. Venting is assumed to be from D/W. The rupture disk was indeed broken.

Unit 2: Sequence and Modeling

Date	Fukushima Local Time	Event	ΔT since SCRAM [h]	ENEA Hypotheses
11/03/11	14:46:00	SCRAM		
14/03/11	16:16:00	Core uncovery	73.50	
15/03/11	0:02:00	Venting, disk status unknown	81.27	Disk rupture
15/03/11	0:12:00	End venting	81.43	

In Unit 2 the status of the rupture is assumed to be broken. It is highly probable that the core was recovered after 4.5 h.

Unit 3: Sequence and Modeling

Date	Fukushima Local Time	Event	ΔT since SCRAM [h]	ENEA Hypotheses
11/03/11	14:46:00	SCRAM		
13/03/11	8:46:00	Core uncovery	42.00	
13/03/11	9:20:00	Venting, disk rupture/rem.	42.57	Drywell venting
13/03/11	11:17:00	End venting, closure valve	44.45	
13/03/11	12:30:00	Venting, opening valve	45.67	Neglected
13/03/11	15:00:00	End venting, closure valve	48.17	
13/03/11	20:10:00	Venting, opening valve	53.83	Neglected
14/03/11	1:00:00	End Venting, closure valve	58.67	
14/03/11	6:10:00	Venting, opening valve	63.83	Neglected
14/03/11	6:10:00	End venting, closure valve	63.83	
14/03/11	11:01:00	Explosion	68.68	

In Unit 3 three ventings were neglected because it is not clear if the line valves were open or not. The core was probably recovered after 2.5 hours. The status of the rupture disk is unknown.

3. Results

ENEA has calculated the ST release curves for 81 nuclides. Table 3 reports, as an example, the ENEA and several published estimates of the total cumulative STs (Bq) for five isotopes. The first column has been colored as follow:
Red nuclides with $\tau_{1/2} > 10$ days, Green nuclides with $\tau_{1/2} < 2$ days, White nuclides with intermediate $\tau_{1/2}$ days.

		ENEA	ENEA	ENEA	ENEA		
$T_{1/2}$ [d]	Nuclide	RASCAL 4.2 U1	RASCAL 4.2 U2	RASCAL 4.2 U3	RASCAL 4.2 total	RASCAL 4.2 total	NSC 22/08/11
3.93E+03	**Kr-85**	6.20E+15	9.76E+15	1.21E+16	2.81E+16		
5.25E+00	**Xe-133**	1.74E+18	1.52E+18	2.31E+18	5.56E+18		
8.02E+00	**I-131**	4.89E+16	9.12E+16	5.84E+16	1.99E+17	2.00E+17	1.30E+17
1.10E+04	**Cs-137**	4.15E+15	1.20E+16	5.25E+15	2.14E+16	2.17E+16	1.10E+16
1.74E-02	**Te-131**	1.06E+15	5.38E+14	2.50E+14	1.85E+15		
			2011	**2012**			
$T_{1/2}$ [d]	Nuclide	IRSN d	ENEA / IRSN d Ratio	ENEA/ IRSN d Ratio	IRSN i	TEPCO MELCOR 2011	TEPCO i 2012
3.93E+03	**Kr-85**	2.0E+16	**1.41**	**0.86**			
5.25E+00	**Xe-133**	2.0E+18	**2.78**	**0.94**	1.21E+19	1.10E+19	
8.02E+00	**I-131**	9.0E+16	**2.21**	**1.01**	1.03E+17	1.60E+17	4.70E+17
1.10E+04	**Cs-137**	1.0E+16	**2.14**	**1.04**		1.50E+16	9.00E+15
1.74E-02	**Te-131**	5.0E+14	**3.70**	**2.21**		9.70E+13	

Table 3: Cumulative Source Term [Bq] for some isotopes

Table 3 shows:

- ✓ A good agreement between ENEA and IRSN-2011 STs <u>for the red nuclides</u>;.
- ✓ A lesser agreement between ENEA and IRSN-2011 STs <u>for the green nuclides</u>;
- ✓ A good agreement between ENEA and IRSN-2012 STs <u>for all nuclides</u>.

Figure 2 reports the result of the time-dependent total cumulative activities of I-131 and Cs-137 released to the atmosphere as obtained by RASCAL 4.2.

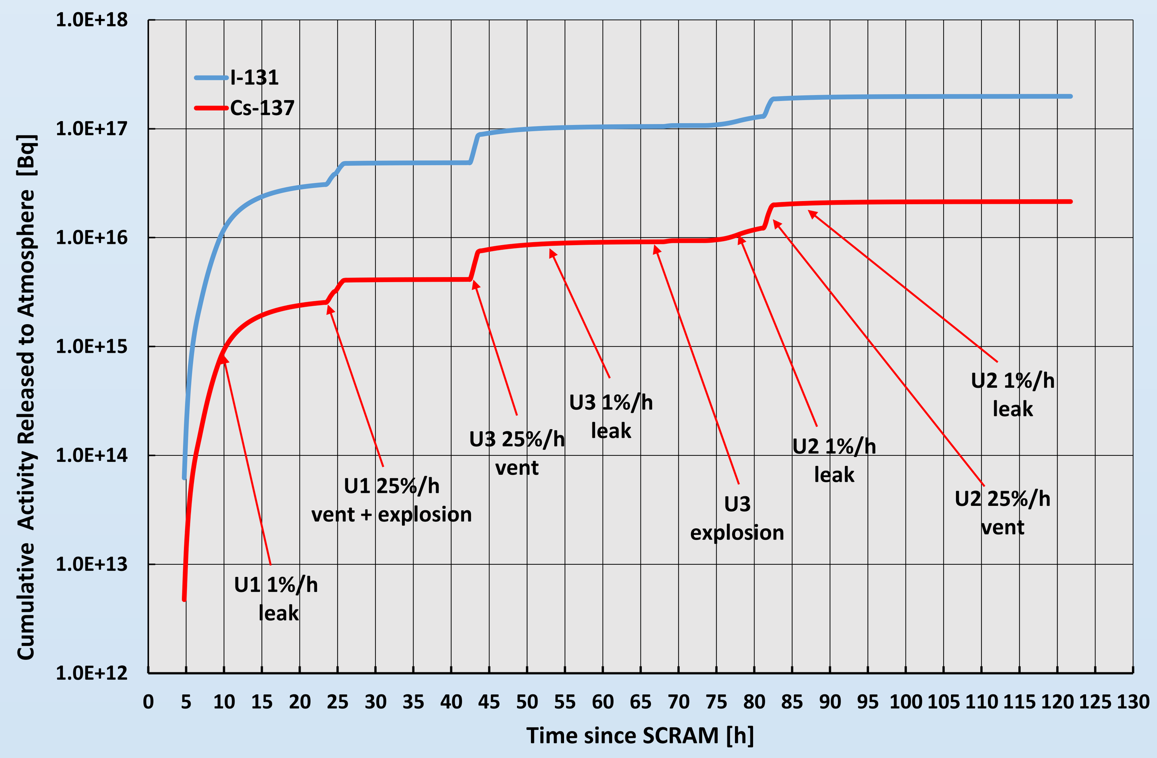

Figure 2: Total cumulative activity released to the atmosphere of I-131 and Cs-137

Uncertainty analysis

It was performed an uncertainty analysis to evaluate the global uncertainty of the ST for two nuclides. The parameters chosen are:

- **Pc** accident containment leakage [%/h];
- **Pv** venting leak rate [%/h];
- **Pe** explosion leak rate [%/h];
- **Tl** duration fo the release [h];
- **Tu** time to core dewatering [h];

The choice of the parameters variability is reported in Table 4.

	Parameters variability				
Unit	ΔPc	ΔPv	ΔPe	ΔT_l	ΔT_u
[-]	[%/h]	[%/h]	[%/h]	[min]	[h]
1	±0.5	±5	±10	±15	±2.0
2	±0.5	±5	-	±15	±6.5
3	±0.5	±5	±10	±15	±5.0

Table 4: Parameters range for the uncertainty study

	Nuclide	Unperturbed ST	Uncertainty
Nature of uncertainties	[-]	[Bq]	[% of unperturbed value]
Deterministic	Cs-137	2.14E+16	**± 34**
	I-131	1.98E+17	**± 34**
Stochastic	Cs-137	2.14E+16	**± 21**
	I-131	1.98E+17	**± 20**

Table 5: Global uncertainty values

4. Conclusion

RASCAL 4.2 can lead to good estimates of the ST in the case of severe accidents like the CSBOs at the Fukushima site. However, the experience of the user is of fundamental importance. In particular, a sound (i.e. realistic) time sequence of release events is necessary.
RASCAL analysis may also be seen as an *a posteriori* validation of the hypothesis that *the material ejected during the ventings and/or explosions was of D/W nature or origin, and not of W/W.*

Full ENEA Report available at: http://openarchive.enea.it/bitstream/handle/10840/4840/UTFISSM-P000-017_rev.1.pdf?sequence=4