Antonio Guglielmelli – Antonio Cervone – Federico Rocchi – V. Creach – G. Ortega Nicaise

Intercomparison of PERSAN 4 and RASCAL 4.3 Source Term evaluation for a PWR LOCA Scenario

ENEA
Italian National Agency for New Technologies Energy and Sustainable Economic Development
IRSN INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

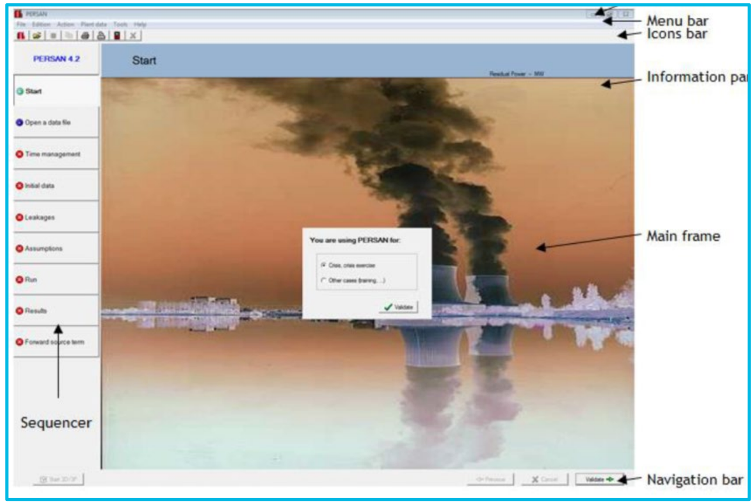
EUROSAFE 2019

Summary

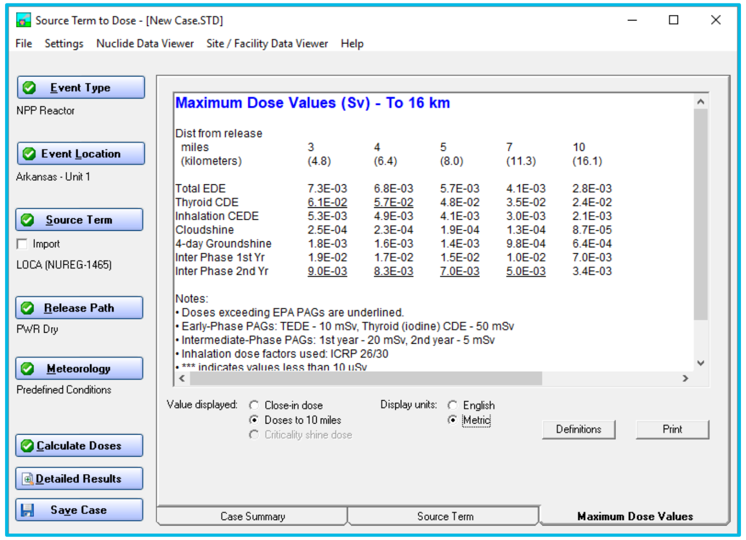
- **Introduction**
- **Technical Scenario description**
  - NPP status and accident initiator events
  - Core inventory
  - Severe accident sequence
- **Code descriptions and sequence modeling**
  - RASCAL 4.3
  - PERSAN 4
- **Results**
- **Conclusions**

Introduction

- Problem: different fast-running codes could provide distinct results due to the different methods and options used by the codes themselves;
- Aim: to perform an intercomparison of the ST results provided by **PERSAN 4 and RASCAL 4.3** fast-running codes to evaluate the possible different results;
- Data: the SA sequence used for the analysis was proposed by IRSN in a real time excercise within the FASTNET Euratom project;
- Sequence: LOCA scenario at a 900 MWe PWR.



PERSAN 4



RASCAL 4.3

ENEA
Italian National Agency for New Technologies Energy and Sustainable Economic Development

IRSN INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

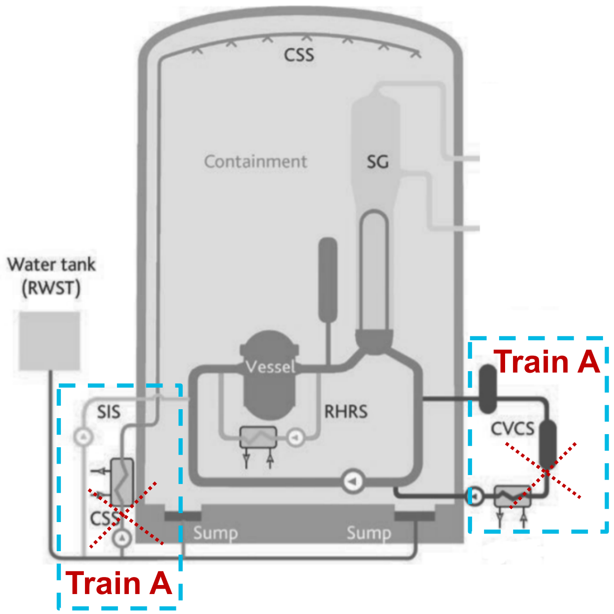
EUROSAFE 2019

NPP status and accident initiator event

- NPP site: The «fictitious» Unit 11 of the Gravelines NPP site.
- NPP information: Graveline site hosts 6 nuclear reactors (CP1 type) each of 900 MWe.

Status of Unit 11 at the beginning of the SA and initiator event

Date	Time	Event	Note	
22/02/2019	07:00	In operation at full power (100% NP)	Boron concentration (14 ppm)	Primary activity (1 GBq/t I131 equiv.)
22/02/2019	07:15	Fire in Electrical Building (sector #L391)	Train B Safety System not available	Train A CSS and CVCS pumps under repair
22/02/2019	07:32	Reactor Trip	Operator applied the Standard Operation Procedures (SOPs)	



Core inventories – results

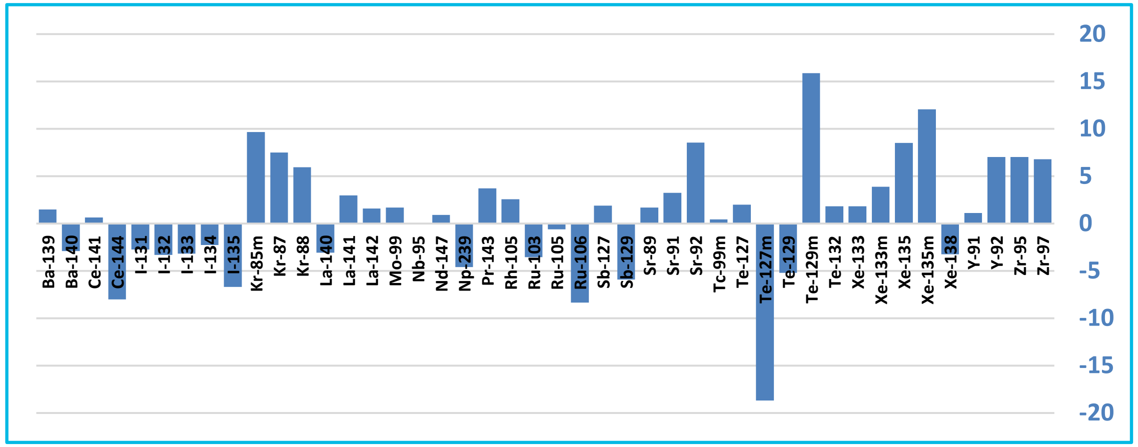
- Aim: check the core inventories used by the two fast-running codes. Different initial core inventories could provide different STs!
- PERSAN 4: core inventory based on Blayais Unit 1, Cycle 23 at EOL (GARANCE MOX fuel hybrid management);
- RASCAL 4.3: core inventory based on default PWR core scaled with the Gravelines thermal power (2785 MWth);
- Results:
  - The single isotopic variations are below about 20 – 30%;
  - Only two nuclides show a difference of about a factor 2.
  - Difference between RASCAL and PERSAN total core inventory is negligible (~ 2.3%);

Core activity – RASCAL 4.3 vs PERSAN 4

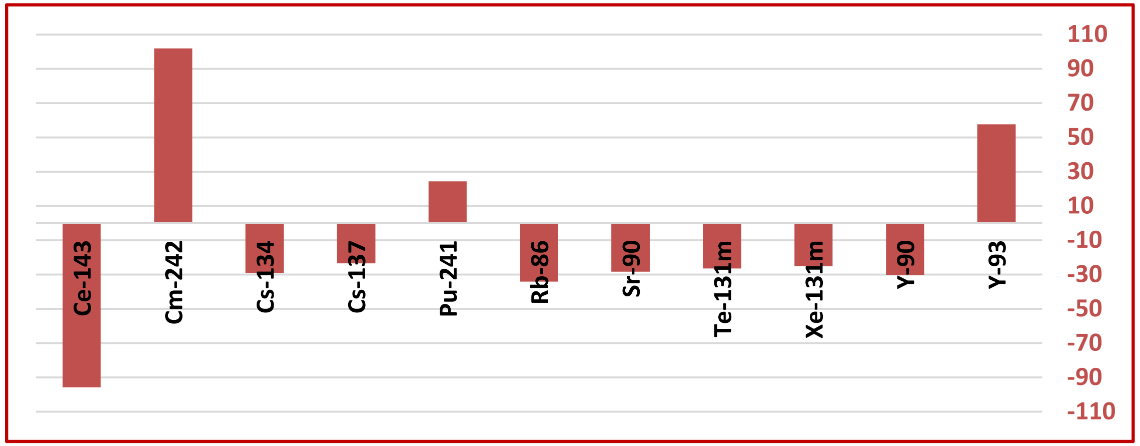
Isotopes	Activity (PERSAN)	Activity (RASCAL)	Var	Isotopes	Activity (PERSAN)	Activity (RASCAL)	Var
(-)	(Bq)	(Bq)	(%)	(-)	(Bq)	(Bq)	(%)
Ba-139	4.95E+18	4.87E+18	1.50	Ru-103	4.31E+18	4.47E+18	-3.56
Ba-140	4.76E+18	4.90E+18	-2.90	Ru-105	3.13E+18	3.15E+18	-0.62
Ce-141	4.55E+18	4.52E+18	0.66	Ru-106	1.46E+18	1.60E+18	-8.34
Ce-143	1.77E+17	4.12E+18	-95.71	Sb-127	2.51E+17	2.46E+17	1.91
Ce-144	3.36E+18	3.65E+18	-8.00	Sb-129	8.42E+17	8.94E+17	-5.90
Cm-242	2.33E+17	1.15E+17	101.88	Sr-89	2.53E+18	2.48E+18	1.68
Cs-134	3.42E+17	4.83E+17	-29.14	Sr-90	1.77E+17	2.46E+17	-28.30
Cs-136	1.64E+17	1.54E+17	6.72	Sr-91	3.20E+18	3.10E+18	3.23
Cs-137	2.57E+17	3.35E+17	-23.40	Sr-92	3.62E+18	3.34E+18	8.56
I-131	2.68E+18	2.75E+18	-2.73	Tc-99m	4.52E+18	4.50E+18	0.46
I-132	3.87E+18	4.00E+18	-3.31	Te-127	2.48E+17	2.43E+17	1.99
I-133	5.41E+18	5.59E+18	-3.19	Te-127m	3.33E+16	4.09E+16	-18.70
I-134	6.01E+18	6.15E+18	-2.26	Te-129	8.06E+17	8.50E+17	-5.21
I-135	4.98E+18	5.34E+18	-6.69	Te-129m	2.01E+17	1.73E+17	15.89
Kr83m	3.26E+17	3.14E+17	3.73	Te-131m	4.10E+17	5.57E+17	-26.44
Kr85	2.46E+16	2.86E+16	-14.27	Te-132	4.00E+18	3.93E+18	1.84
Kr-85m	6.97E+17	6.36E+17	9.67	Xe-131m	2.81E+16	3.76E+16	-25.23
Kr-87	1.36E+18	1.27E+18	7.49	Xe-133	5.70E+18	5.60E+18	1.82
Kr-88	1.86E+18	1.75E+18	5.94	Xe-133m	1.84E+17	1.77E+17	3.88
La-140	4.89E+18	5.05E+18	-3.06	Xe-135	1.59E+18	1.46E+18	8.53
La-141	4.59E+18	4.46E+18	2.96	Xe-135m	1.33E+18	1.19E+18	12.06
La-142	4.41E+18	4.34E+18	1.58	Xe-138	4.55E+18	4.70E+18	-3.23
Mo-99	5.17E+18	5.08E+18	1.70	Y-90	1.79E+17	2.57E+17	-30.19
Nb-95	4.64E+18	4.64E+18	-0.02	Y-91	3.30E+18	3.27E+18	1.13
Nd-147	1.82E+18	1.80E+18	0.92	Y-92	3.60E+18	3.36E+18	7.04
Np-239	5.59E+19	5.86E+19	-4.59	Y-93	4.09E+18	2.60E+18	57.53
Pr-143	4.23E+18	4.08E+18	3.72	Zr-95	4.90E+18	4.58E+18	7.02
Pu-241	5.46E+17	4.39E+17	24.33	Zr-97	4.65E+18	4.36E+18	6.79
Rb-86	3.59E+15	5.45E+15	-34.22	TOT	1.99E+20	2.04E+20	-2.33
Rh-105	2.97E+18	2.90E+18	2.57				

Core inventories – insights

- The intercomparison was performed on those nuclides that are included in both RASCAL and PERSAN inventories;
- The total number of radionuclides of the full PERSAN 4 database inventory is 720, that of RASCAL 4.3 database is 58;
- PERSAN 4 can in any case resort to different sets of initial inventories with a variable number of isotopes;



Core inventory radionuclides with a relative difference lower than 20%.



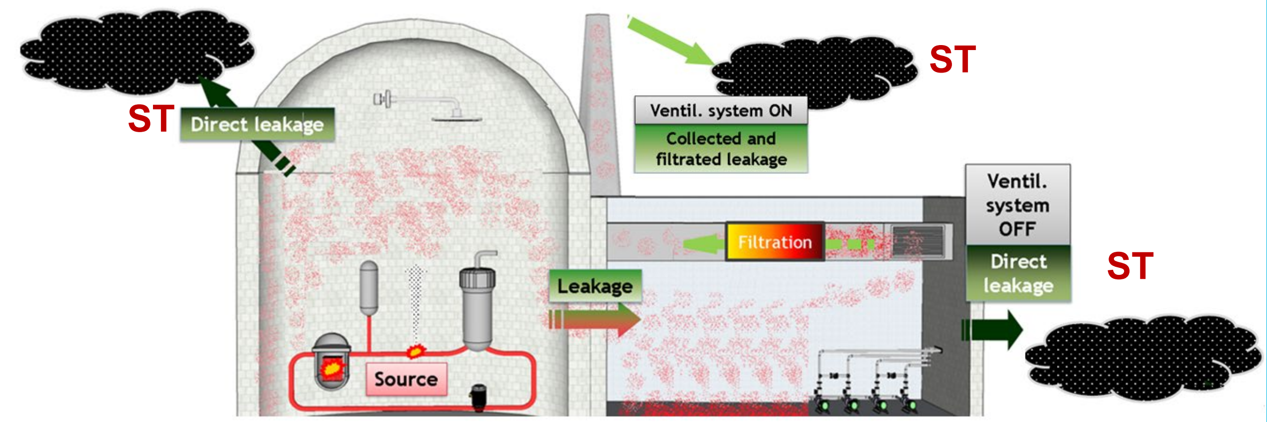
Core inventory radionuclides with a relative difference higher than 20%.

Severe Accident Sequence – ST evaluation scenario

- Data: IRSN made available information in the form of periodic reports and exercise messagges during the FASTNET exercise;
- ST evaluation: excercise 2 indicated three time steps of the sequence at which to evaluate STs at different times since the initial release.

ST evaluation	Information availability	Time since the initial release
ST#1	2h30 after Reactor Trip	24 hours
ST#2	4h30 after Reactor Trip	24 hours
ST#3	33h00 after Reactor Trip	7 days

Possible Source Term emission points (LOCA scenario)



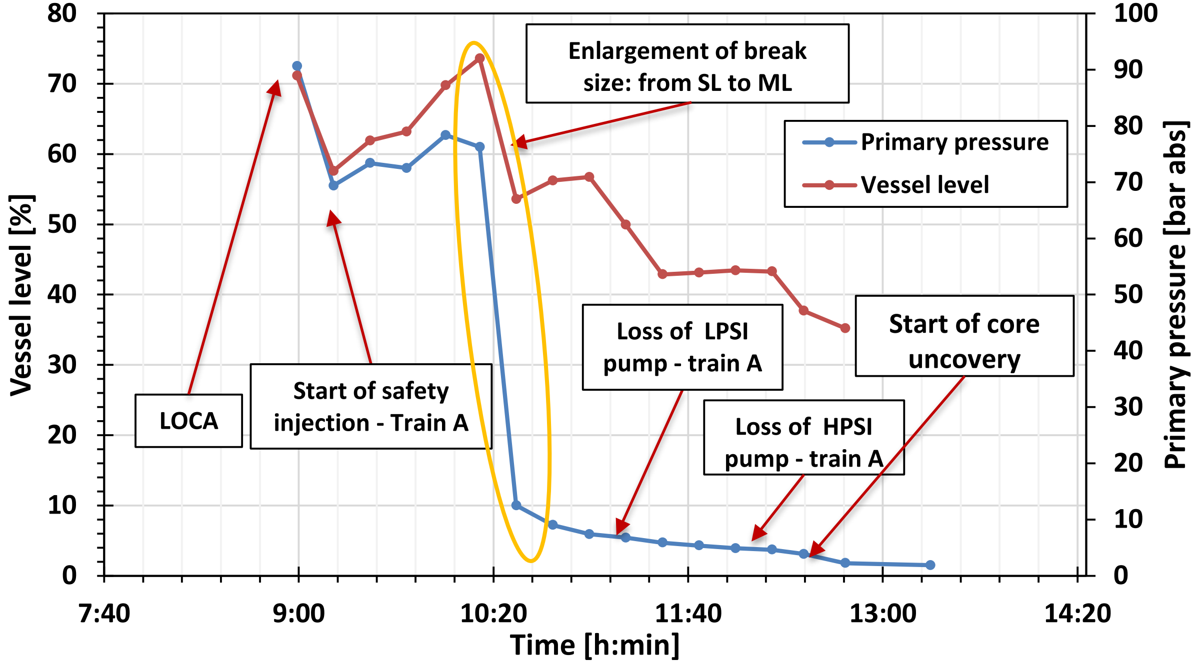
Severe Accident Sequence – Timetable of the scenario

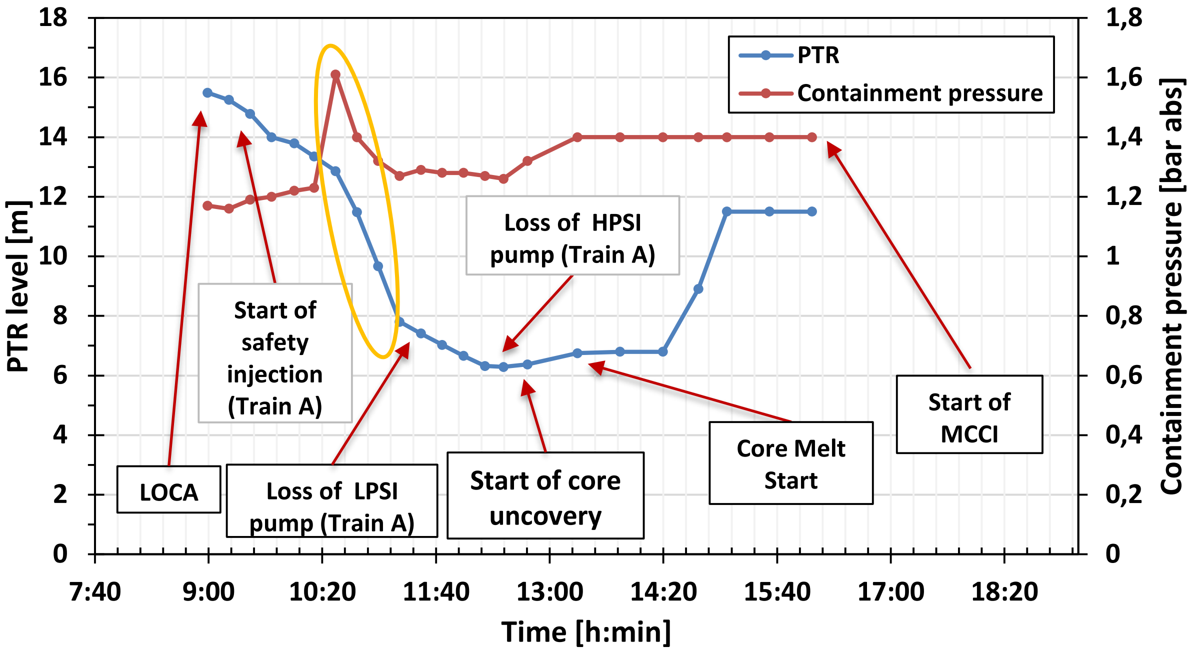
Time since SCRAM	Real Time	Event	Source
0	7h32	Reactor Trip (as required by procedures)	State of the Unit at the beginning of the accident(22/02/2019 @ 09:00)
43	8h15	Total shutdown of Train B	Technical Scenario - IRSN
48	8h20	Primary break, cold leg	Technical Scenario - IRSN
55	8h27	Pressure increase in the reactor building	State of the Unit at the beginning of the accident (22/02/2019 @ 09:00)
1h18	8h50	DVN and DVK[2] off, DVW[2] in operation	State of the Containment (Message #1 22/02/2019 @ 08:50)
1h28	9h00	ECP4 – HPSI in operation (On site emergency plan)	SESAME 4.0 Acquisition (Message #1 19/02/2019 @ 09:00)
1h43	9h15	Start of safety injection (train A)	SESAME 4.0 Acquisition (Message #2 19/02/2019 @ 09:15)
1h48	9h20	Containment isolation 1st phase	State of the Containment (Message #2 22/02/2019 @ 09:20)
2h28	**10h00**	**First ST Evaluation Request: ST#1**	
2h43	10h15	ECP4, Vessel level, top of the hot leg	SESAME 4.0 Acquisition (Message #6 22/02/2019 @ 10:15)
2h48	10h20	DVN in operation, DVK and DVW off	State of the Containment (Message #3 22/02/2019 @ 09:50)
3h43	11h15	Loss of train A LPSI pump	SESAME 4.0 Acquisition (Message #10 22/02/2019 @ 11:15)
4h28	**12h00**	**Second ST Evaluation Request: ST#2**	
4h28	12h00	Water makeup to PTR tank (planned)	SESAME 4.0 Acquisition (Message #13 22/02/2019 @ 12:00)
4h43	12h15	Loss of train A HPSI pump	SESAME 4.0 Acquisition (Message #14 22/02/2019 @ 12:15)
4h56	12h28	Start of core uncovery (3.1 bar abs)	SESAME 4.0 Acquisition (Message #15 22/02/2019 @ 12:28)
5h14	12h45	Water make up to PTR tank	SESAME 4.0 Acquisition (Message #16 22/02/2019 @ 12:45)
5h28	13h20	SAMG – Core Melt Start	SESAME 4.0 Acquisition (Message #17 22/02/2019 @ 13:20)
5h58	13h50	Restart of RCV	SESAME 4.0 Acquisition (Message #18 22/02/2019 @ 13:50)
6h08	14h00	Level 2 alarm on KRT detection channel, acitivty in envir.	State of the Containment (Message #9 22/02/2019 @ 14:00)
6h53	14h45	RCV (train A) in operation but low flowrate	SESAME 4.0 Acquisition (Message #20 22/02/2019 @ 14:45)
7h13	15h05	Stop of RCV (train A)	SESAME 4.0 Acquisition (Message #21 22/02/2019 @ 15:05)
7h43	15h35	First corium slump into the vessel lower head	Exercise #2 Technical scenario IRSN
8h08	**16h00**	**Third ST Evaluation Request: ST#3**	
8h38	16h30	Vessel failure – start of MCCI	Exercise #2 Technical scenario IRSN
21h38	05h30	Rupture of lateral walls of the cavity	Exercise #2 Technical scenario IRSN
33h08	17h00	Raft break-through	Exercise #2 Technical scenario IRSN

[1] DVN is the auxiliaries buildings ventilation system, DVK is the fuel building ventilation system and DVW is the connection building ventilation system.

Severe Accident Sequence – Time-dependent parameters

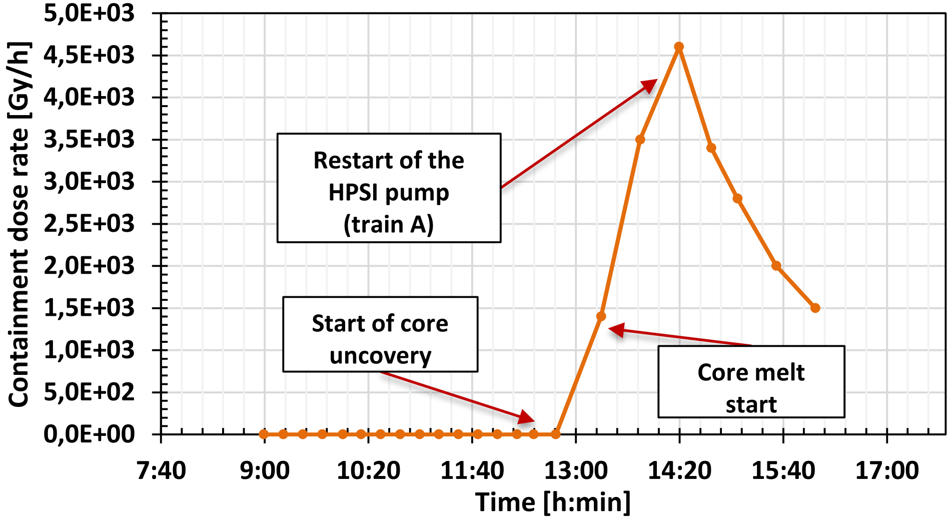
✓ After a LOCA enlargment (from SL to ML) there is a sharp decrease of the primary pressure (~ –85%) and a moderate decrease of the vessel level (~ -27%);

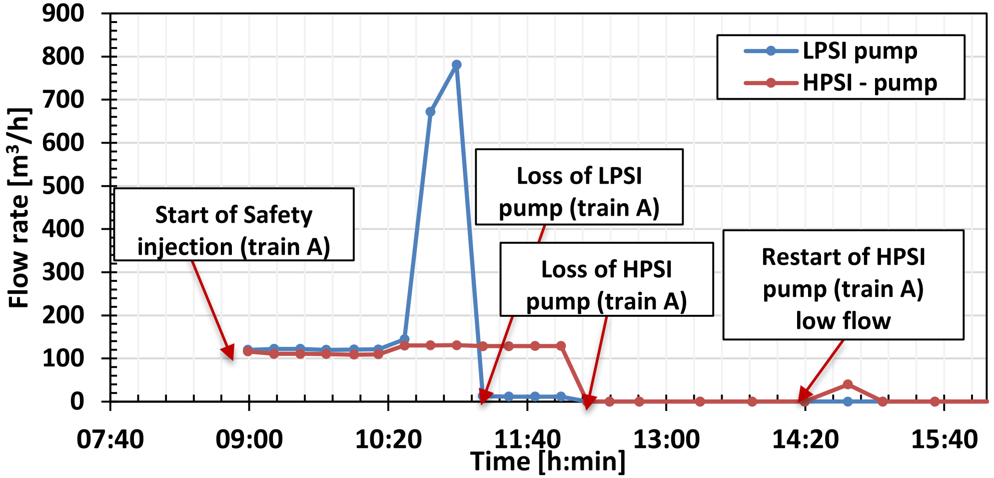


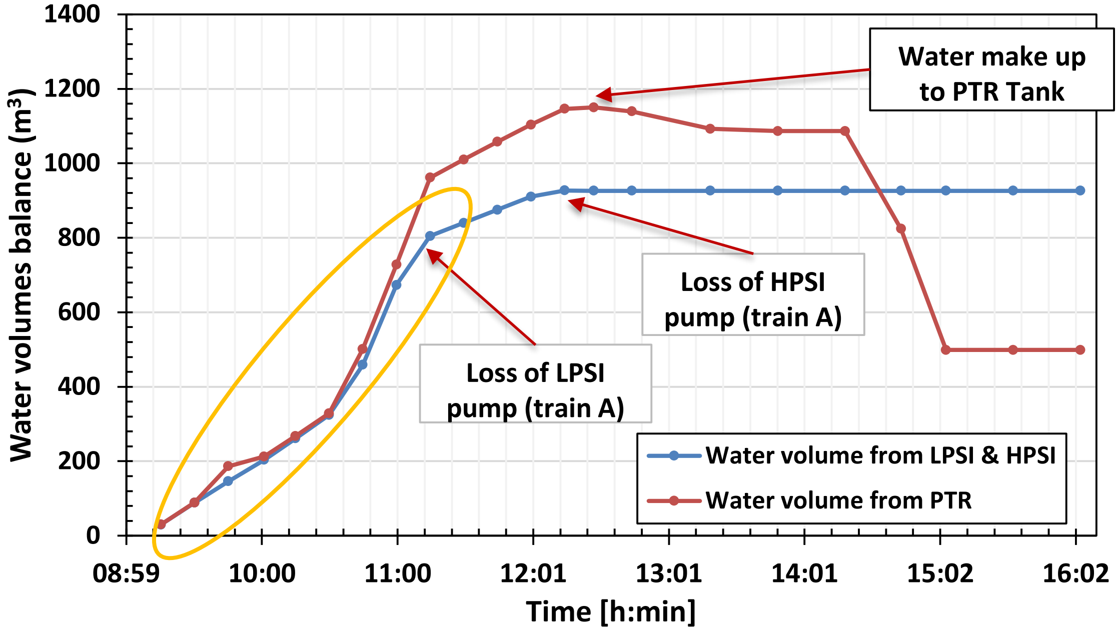


✓ After the LOCA enlargment there is a moderate increase of the containment pressure (~ +30%) and a moderate decrease of the PTR tank level (~ –40%);

Severe Accident Sequence – Time-dependent parameters



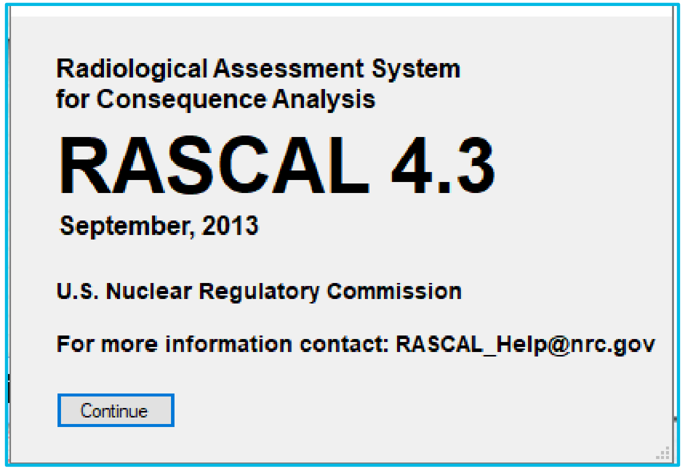


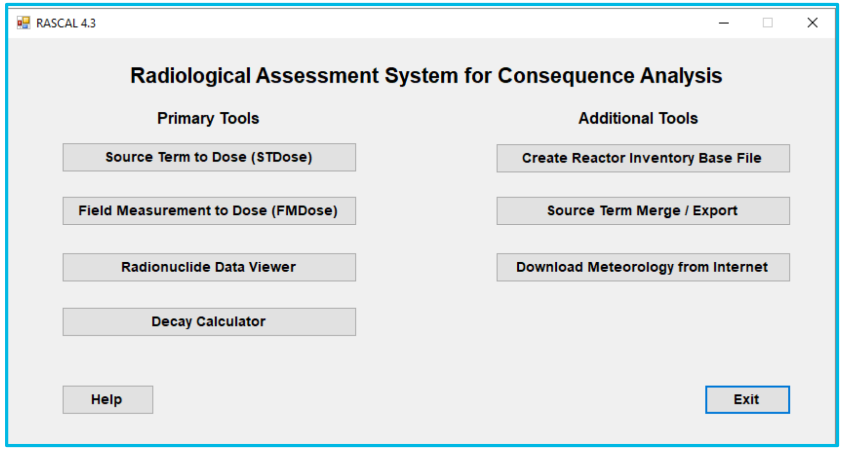


✓ Before the water make up, all the water taken from PTR tank was used to feed the ECCS by means of the LPSI and HPSI pumps (train A);

Code descriptions – RASCAL 4.3

- RASCAL 4.3 is a fast-running tool developed by Athey Consulting for the Protective Measures Team of the **U.S. NRC** Operation Center;
- RASCAL 4.3 is the reference NRC tool for the assessment of the RC of an hypothetical SA;
- The code was initially developed 25 years ago to aid decision-making on countermeasures to the public;
- The 4.3 version extends the atmospheric dispersion to 160 km, increases the calculation duration to 96 hours and adds the capability to import, merge and export STs;





Code descriptions – RASCAL 4.3 (Source Term evaluation)

- The time-dependent ST is evaluated with a simple algebraic expression in which the several terms are multiplied together:

$$S_i(t) = I_i \cdot a_i(t) \cdot \prod_{n=1}^{N} RDF(t)_{i,n} \cdot LF_i(t)$$

- Where:
  - I_i is the initial core inventory of the *ith* radionuclide;
  - $a_i(t)$ is the core release fraction of the *ith* radionuclide that depends on the time progression of the accident (i.e., gap release, early in-vessel, ex-vessel, late in-vessel);
  - $RDF(t)_{i,n}$ is the contribution that the *nth* reduction mechanism (i.e., radioactive decay, containment spray, containment natural processes, Ice Condenser, etc.) has on the *ith* radionuclide;
  - LF_i is the fraction of the *ith* radionuclide in the containment that is released to the atmosphere.

Code descriptions – RASCAL 4.3 (Reduction Factors, RDFs)

- RASCAL 4.3 assumes that 95% of the radioiodine and all FPs besides the NGs are in aeresol form;
- Therefore, the reduction mechanisms are assumed to affect equally all FPs except NGs;
- The RDFs for natural deposition and sprays are expressed with an exponential decay law where the decay constant changes with the time;
- The other RDFs have a constant value with the constraint that the total value of RDF has to be greater than 0.001;
- Filters and containment sprays have a lower limit on the RDF of 0.01 and 0.03 respectively.

Reduction mechanism or cause	Reduction Factor Multiplier
Containment sprays (reference: NUREG/CR-4722, Figure 5)	First 0.25 h: exp(-12t) After 0.25 h: exp(-6t)
Containment natural processes during hold-up (reference: NUREG-1150, Appendix B)	First 1.75 h: exp(-1.2t) 1.75 to 2.25 h: exp(-0.64t) After 2.25 h: exp(-0.15t)
PWR Ice condenser - no fans or recirculation	0.5
PWR Ice condenser - 1 h or more recirculation	0.25
BWR release pathway from drywell via wet well with sub-cooled pool water	0.01
BWR release pathway from drywell via wet well with saturated pool water	0.05
Plate out for containment bypass pathway	0.4
Steam generator tube rupture - partitioned (break underwater)	Partitioning factor (steam concentration as fraction of SG water concentration) 0.02
Steam generator tube rupture - not partitioned (break above water level)	Partitioning factor (steam concentration as fraction of SG water concentration) 0.5
Steam generator tube rupture - condenser off gas release	0.05
Steam generator tube rupture - safety relief valve release	1
Filters	0.01
Lower limit on reduction multiplier (except for filters)	0.001
Lower limit on reduction multiplier for containment sprays (reference: NUREG/CR-4722, Figure 5)	0.03

Code descriptions – RASCAL 4.3 Modules

- The ST was evaluated with the «Source Term to Dose» module which requires four sub-tools: Event type, Event Location, Source Term, Release path and Metereology;
- *Event type*:
  - Define the type of affected plant (i.e., NPP, Spent Fuel, Fuel Cycle, UF6, Criticality Event).
- *Event location*:
  - Locates in space the NPP and defines the data to evaluate the inventory. The options are:
    - Load an event location from U.S. NPPs, already defined in the RASCAL database;
    - Define a generic site.
- The strategy adopted is to use a «surrogate» NPP plant.

Code descriptions – RASCAL 4.3 Surrogate NPP

- *Surrogate NPP*:
  - Plant available in RASCAL 4.3 internal database which differs from the real plant only as regards actual power and actual core average burnup;
  - This means to find among the U.S. fleet a Graveline-like NPP (i.e. 3-loops, 900 MWe, dry containment);
  - Surrogate NPP chosen: Beaver Valley Unit 2;

Parameters	Data
Reactor Type	PWR
Thermal Capacity (MWth)	2900
Reference Unit Power (Net Capacity MWe)	905
Reactor vendor	Westinghouse 3-loop
Containment	
Containment type	PWR, Dry Ambient
Containment volume	50970 m3
Design pressure	3.72E+05 Pa
Steam Generator	
SG type	U-Tube
SG water mass	42184 kg
Fuel	
Number of fuel assemblies	157
Number of fuel rods per assembly	264 (17x17)
Gravelines-like parameters	
Power (MWth)	2785
Core average burn-up (MWd/MTU)	30000

Code descriptions – RASCAL 4.3 Modules

- *Source Term*:
  - Define the methods to estimate the ST;
  - It's possible to choose four sub-modules which differ on the basis of the accident sequence;
  - «LOCA» is the ST method chosen; it's based on reactor conditions and the procedures described in NUREG-1228 and NUREG-1945;

LOCA submodule data - (ST#2, ST#3)

Event	Data	Time	ΔT since SCRAM
Reactor shoutdown	22/02/2019	07:32	00:00
Core uncovered	22/02/2019	13:00	05:28
Method used for core damage estimate			
Core recovered (Yes/No)		No	

  - LOCA requires the SCRAM and core uncovery times, and core recovery, if achieved;
  - LOCA method cannot presently evaluate STs prior to any core dewatering, low releases like that associated to ST#1 – due to leak of primary water into the containment – cannot be dealt with.

Code descriptions – RASCAL 4.3 Release path

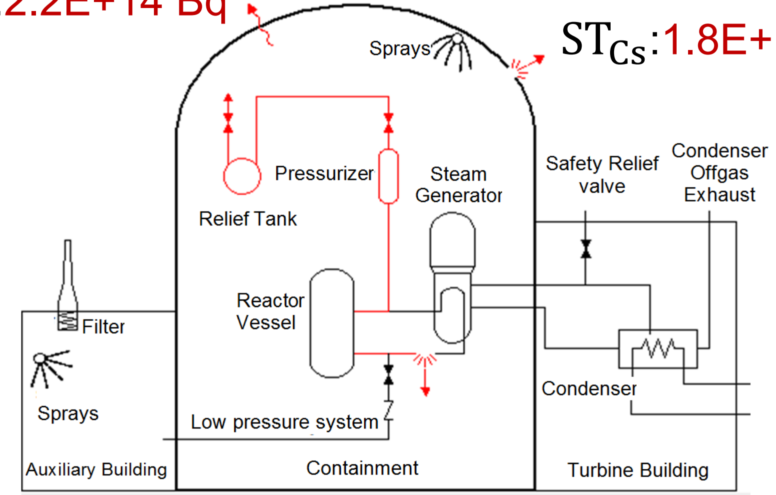
- *Release path*
- Defines the main release path to the environment and the time-dependent events;
  - Leak rate of radionuclides from the containment to the atmosphere, expressed as percentage fraction of containment volume per day;
  - The leak rate value of 0.02%vol/d is the RASCAL nearest seattable value to that adopted by IRSN and EdF (i.e., 0.01624 %vol/d) for an intact containment of a 900 MWe PWR.
  - Total failure event has been chosen in RASCAL to model the effects of a raft breakthrough event;
  - RASCAL does not simulate the status of the ventilation system and MCCI phenomena.

Event	Data	Time	ΔT since SCRAM [h]	[min]	Value
Spray	22/02/2019	13:00	5	28	Off
Leak Rate	22/02/2019	13:00	5	28	0.02 %vol/d
Leak Rate	24/02/2019	17:00	57	28	Total failure (100% vol/h)

ST#2 (Spray, Leak Rate 22/02/2019); ST#3 (all rows)

ST_I:2.2E+14 Bq

ST_{Cs}:1.8E+13 Bq



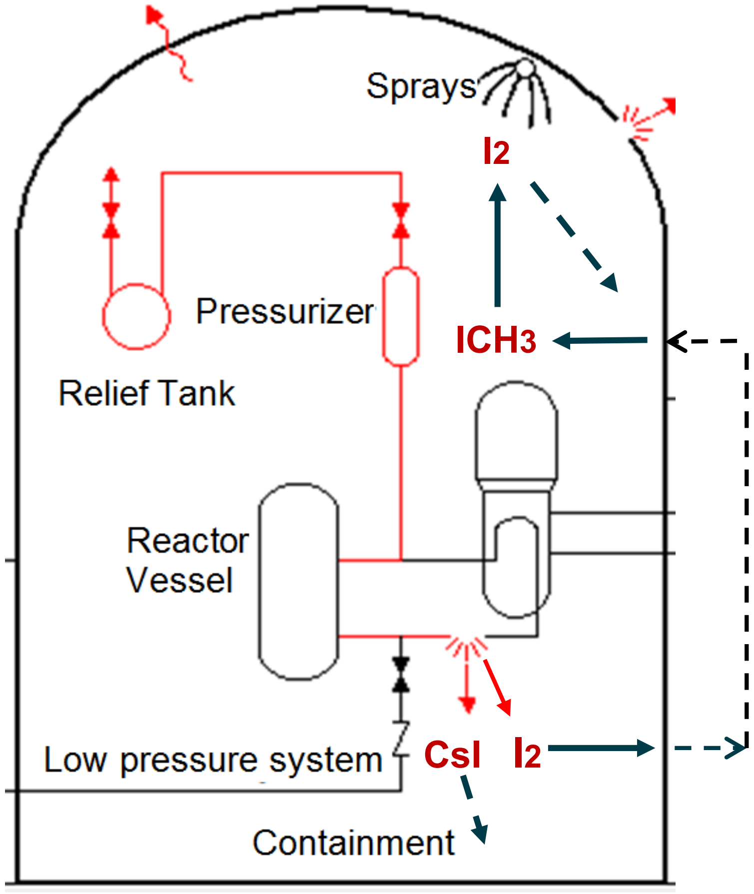
Code descriptions – PERSAN 4

- PERSAN 4 was developed by IRSN and is the reference French fast-running tool to evaluate STs for a LOCA-initiated scenario to a PWR NPP;
- PERSAN 4 was extended to describe accidents at any type of European NPPs (i.e., PWR, BWR, VVER and CANDU) during the FASTNET project;
- It takes into account core damage, retention factors in the primary coolant system, aereosol deposition rates, iodine chemistry, leak rates between containment, auxiliary buildings and the atmosphere;
- The main input parameters are: building leak rates, fuel damage, containment pressure evolution, availability of CSS and of ventilation systems in the auxiliary building;
- The measured building leak rates obtained during containment building periodic tests are used as default input assumptions;
- The models implemented in PERSAN have been validated with ASTEC using a large ensemble of accident scenarios;

Code descriptions – PERSAN 4 Iodine Chemistry

- PERSAN, to the contrary of RASCAL, keeps distinct the various chemical forms of iodine molecules (I_2, IO_x, ICH_3, etc.) through simplified speciation models;

- The models used take into account the CsI, I_2 and ICH_3 species. In detail, the iodine chemistry model considers that:
  - The iodine at the break is constituted by CsI (95%) and I_2 (5%);
  - A fraction (i.e., 10% wt) of I_2 is adsorbed by Reactor Buildings walls and released in ICH_3 form;
  - A fraction of ICH_3 reacts to form I_2 again and the CsI can deposit in the reactor building;
  - I_2 concentration in the gas phase can be reduced by the CSS;
  - I_2 can be filtered by the Iodine Traps and ICH_3 cannot be dropped by the CSS nor filtered.



Code descriptions – PERSAN 4 (Families and Species)

- The code includes several other models for: aerosol deposition, fission product release, containment dose evaluation, releases calculation;
- PERSAN makes calculations from more than 3000 isotopes, with real-time filiation/decay;
- The code splits the elements in five families according to their physical behaviour:

<table>
<tr><th>Families</th><th>Species</th><th>Physical state</th></tr>
<tr><td>Noble gas</td><td>Xe, Kr, He, Ne, Ar, Rn</td><td>Atomic</td></tr>
<tr><td>Volatile aerosol</td><td>Cs, Te, Mo, Rb, Se, Rh, Tc,...
(21 elements)</td><td>Aerosol</td></tr>
<tr><td>Semi-volatile aerosol</td><td>Ba, La, Ru, Sr, Sb, U, Np, Pu, Am,…
(71 elements)</td><td>Aerosol</td></tr>
<tr><td rowspan="4">Halogen species</td><td rowspan="4">I, F, Cl, Br, At</td><td>Aerosol (CsI)</td></tr>
<tr><td>Gaseous (molecular, I_2)</td></tr>
<tr><td>Gaseous (organic, ICH_3)</td></tr>
<tr><td>Aerosol (oxide, IOx)</td></tr>
<tr><td>Other elements</td><td>H, C, N, O, P, S, Se</td><td>-</td></tr>
</table>

Code descriptions – PERSAN 4 (ST evaluation)

- The code estimates the time-dependent ST with a mass balance formula to evaluate, in each reactor compartment, the time dependent amount of each isotope:

$$C_i(t + dt) = C_i(t) + [S_i(t) - D_i(t) - L_i(t) - F_i(t)]\, dt$$

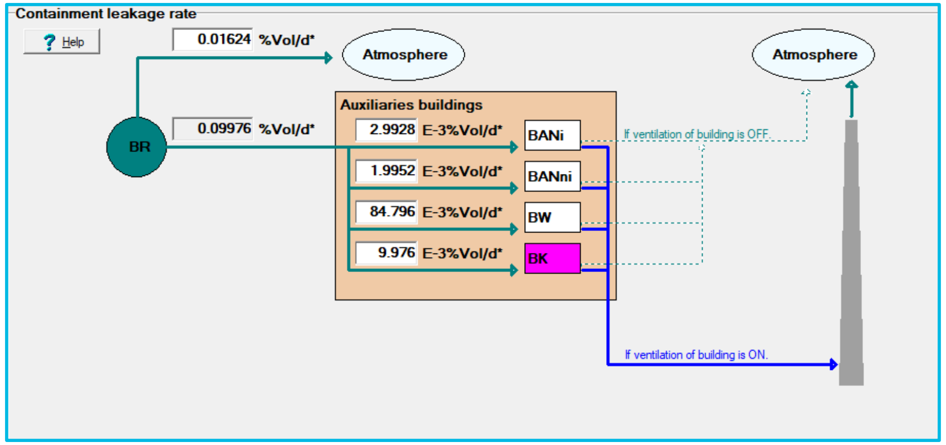
  where:

  - C_i is the mass of *ith* radionuclide in the building;
  - S_i is the source of *ith* radionuclide;
  - D_i is the removal rate of *ith* radionuclide from the building due to processes like natural deposition, sprays, adsorption and chemical reactions;
  - L_i is the leak rate of *ith* radionuclide out of the building;
  - F_i is the filiation/decay term.

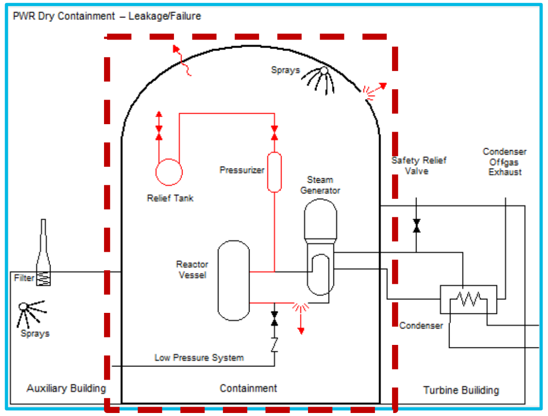
- PERSAN 4 was designed in connection with additional tools (SESAME 4, BRECHEMETRE, SCHEHERASADE, etc) able to predict the evolution of the main plant parameters.

Code descriptions – PERSAN 4 (Leak rate)

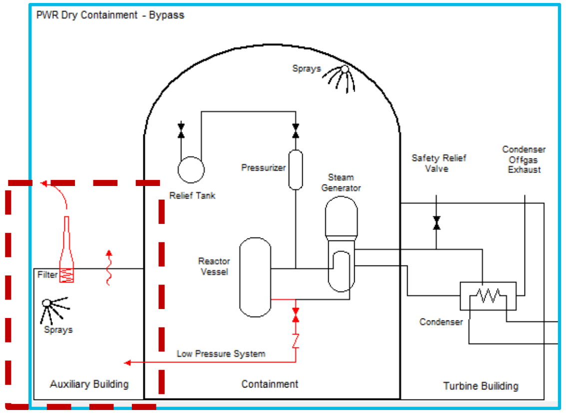
- PERSAN can take into account all possible parallel release paths during an accident (RASCAL only the main one).



Containment and auxiliary building leakage – PERSAN 4



Containment failure – RASCAL 4



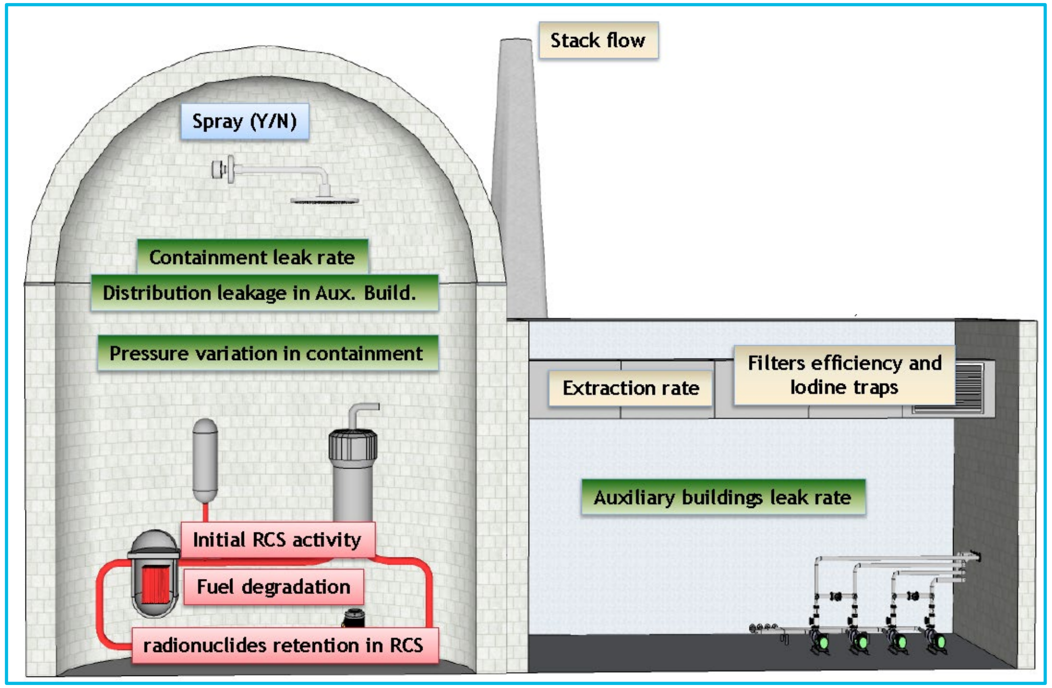
Containment bypass – RASCAL 4

- In nominal conditions:
  - the total flow rate from RB to atmosphere is 8.77E-1 m^3/h;
  - the total flow rate from AB to atmosphere is equal to 5.21E+03 m^3/h (Vent. OFF);
  - the total flow rate from AB to atmosphere is equal to 2.13E+03 m^3/h (Vent. ON).

Sequence modeling – PERSAN 4

- PERSAN 4 assumptions adopted for ST#1, ST#2 and ST#3 have been exctracted from the timetable of the IRSN scenario:

Time assumptions	Date	Time	Note
Reactor Trip	22/02/2019	07:32	ST#1, ST#2, ST#3
Core dewatering	22/02/2019	13:00	ST#2, ST#3
Clad failure start	22/02/2019	13:07	ST#2, ST#3
Core melt start	22/02/2019	13:17	ST#2, ST#3
Core melt end (100%)	22/02/2019	14:46	ST#2, ST#3
Calculation end	23/02/2019	13:33	ST#2
MCCI start	22/02/2019	16:30	ST#3
Raft breakthrought	24/02/2019	17:00	ST#3
Calculation end	26/02/2019	08:20	ST#3



- Initial primary activity: 4.0E+09 Bq/t (eq. of I131);
- Primary system retention: 0% for all chemical species, chemical groups and solid suspensions;
- Spent fuel in SFP: not considered (no accident occurs in the fuel building).

Sequence modeling – PERSAN 4

Core degradation

Date	Time	% clad failure	% core melt	Requests
22/02/2019	07:31	0	0	ST#2, ST#3
22/0272019	13:07	0	0	ST#2, ST#3
22/02/2019	13:16	100	0	ST#2, ST#3
22/0272019	13:17	100	0	ST#2, ST#3
22/02/2019	14:46	100	100	ST#2, ST#3

Containment pressure

Date	Time	Pressure (abs bar)	Requests
22/02/2019	07:31	1	ST#2, ST#3
22/02/2019	07:32	Automatic	ST#2, ST#3
22/02/2019	12:28	1.325	ST#2,ST#3
22/02/2019	12:29	1.4	ST#2, ST#3
22/02/2019	16:29	1.4	ST#3
22/02/2019	16:30	1.6	ST#3
23/02/2019	05:29	1.9	ST#3
23/02/2019	05:30	2.3	ST#3
24/02/2019	17:00	4.7	ST#3
25/02/2019	17:00	1.7	ST#3

Stack flow (ST#2, ST#3)

Date	Time	Flow (E3 m3/h)
22/02/2019	07:31	213
22/02/2019	07:32	239
22/02/2019	07:50	209
22/02/2019	09:30	197

Containment spray system

Date	Time	Trains number	Sections
22/02/2019	07:31	0	ST#2, ST#3
22/02/2019	07:32	Automatic	ST#2, ST#3
22/02/2019	12:28	0	ST#2, ST#3

Ventilation system

Ventilation: DVN iode (ST#2, ST#3)

Date	Time	Operation	Flow ($E3\ m^3/h$)	Filtering					
				VHE	I_2	ICH_3	IOx	NG	Other
22/02/2019	07:31	Not switched IT	18.8	1000					
22/02/2019	08:00	Switchetd IT	18.8	1000	100	10	1	1	1

Ventilation: DVN non iode (ST#2, ST#3)

Date	Time	Operation	Flow ($E3\ m^3/h$)	Filtering					
				VHE	I_2	ICH_3	IOx	NG	Other
22/02/2019	07:31	ON	178	1000					

Ventilation: DVW (ST#2, ST#3)

Date	Time	Operation	Flow ($E3\ m^3/h$)	Filtering					
				VHE	I_2	ICH_3	IOx	NG	Other
22/02/2019	07:31	Normal	12	1000					
22/02/2019	08:00	Accidental	12	1000	1000	100	1	1	1
22/02/2019	09:30	OFF	0						

Ventilation: DVK (ST#2, ST#3)

Date	Time	Operation	Flow ($E3\ m^3/h$)	Filtering					
				VHE	I_2	ICH_3	IOx	NG	Other
22/02/2019	07:31	Normal	30	1000					
22/02/2019	07:50	OFF	0						

- Ventilation, filters and iodine traps options:
  - Not switched IT: HEPA filters efficiency is set to 1000, traps efficiency unavailable for others species (I2, ICH3, IOx, NG);
  - Switched IT: HEPA filters efficiency is set ot 1000, traps efficiency is set to 100 10 1 1 1 for other species;
  - ON: ventilation flow rate, filters efficiency and iodine traps are set to a default value derived from PERSAN plant data;
  - OFF: ventilation flow rate is set to 0 and filters for all species are unavailable;
  - Normal: ventilation flow rate and HEPA filters efficiency is set to a default value, filters and iodine traps are unavailable.
  - Accidental: ventilation flow rate and filters and traps data derived from PERSAN plant data;

Results – ST#1

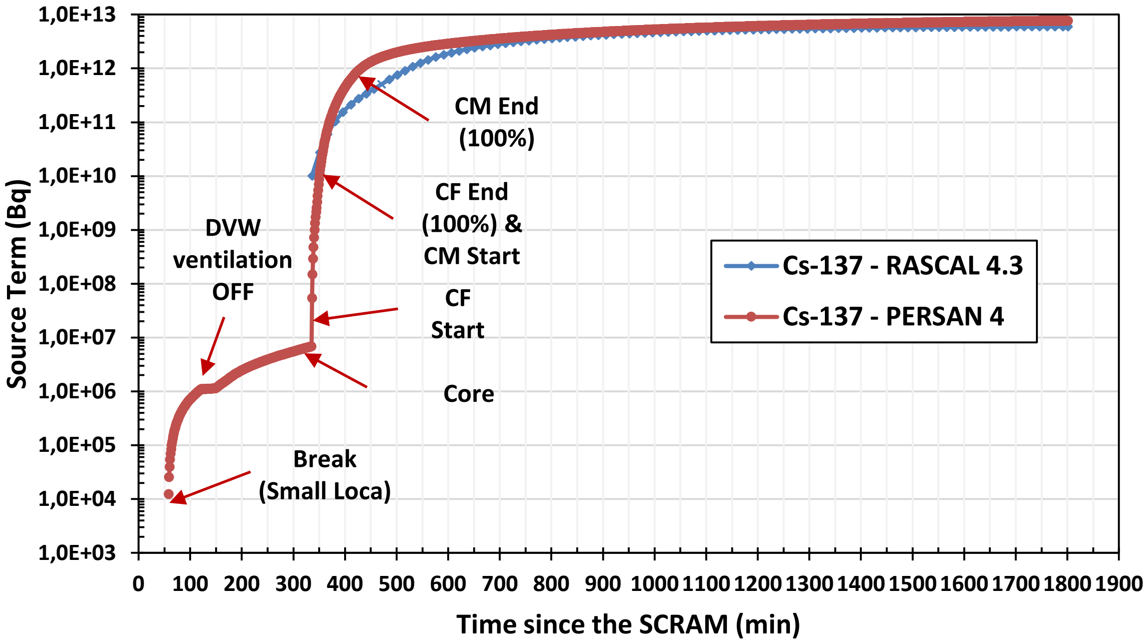
- The results from the two codes have been compared both in terms of overall ST time-dependent releases and in terms of radionuclide contribution to the overall ST.
- ST#1 results **(evaluation of the ST 24 hours after the RT with information available at 10h00)**
  - PERSAN:

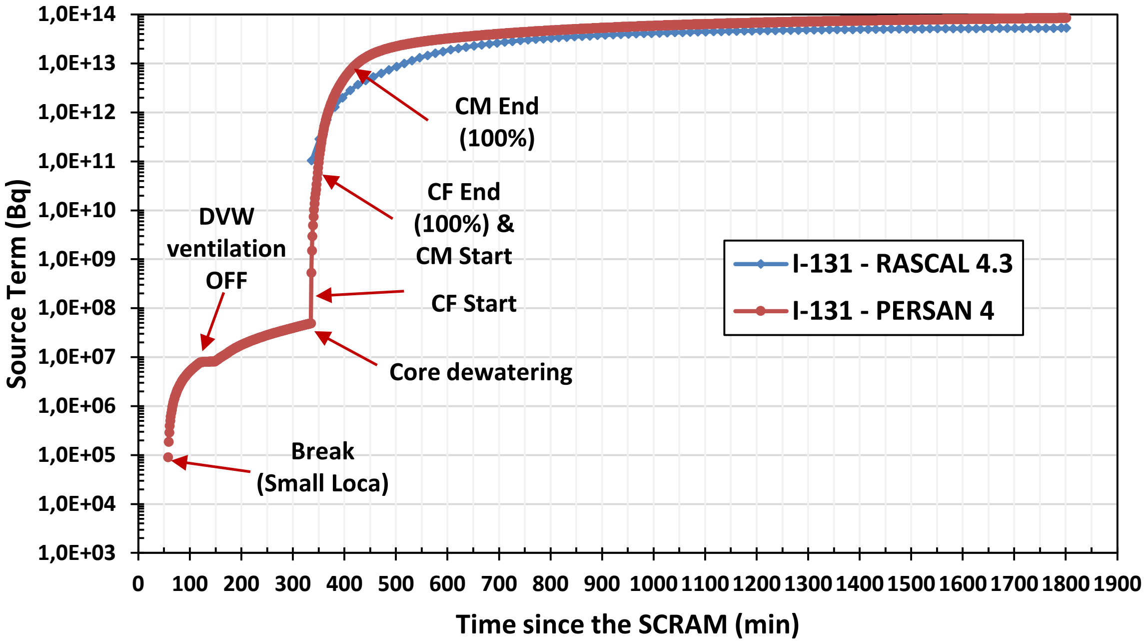
Chemical Class	**Value [Bq]**	**Chemical class**	**Vaue [Bq]**
Noble gas	1.54E+09	**Cesium**	1.77E+09
Iodine	1.00E+09	**Tellurium**	0

  - The intercomparison with RASCAL 4 has not been made because the code does not evaluate STs before any core-dewatering.

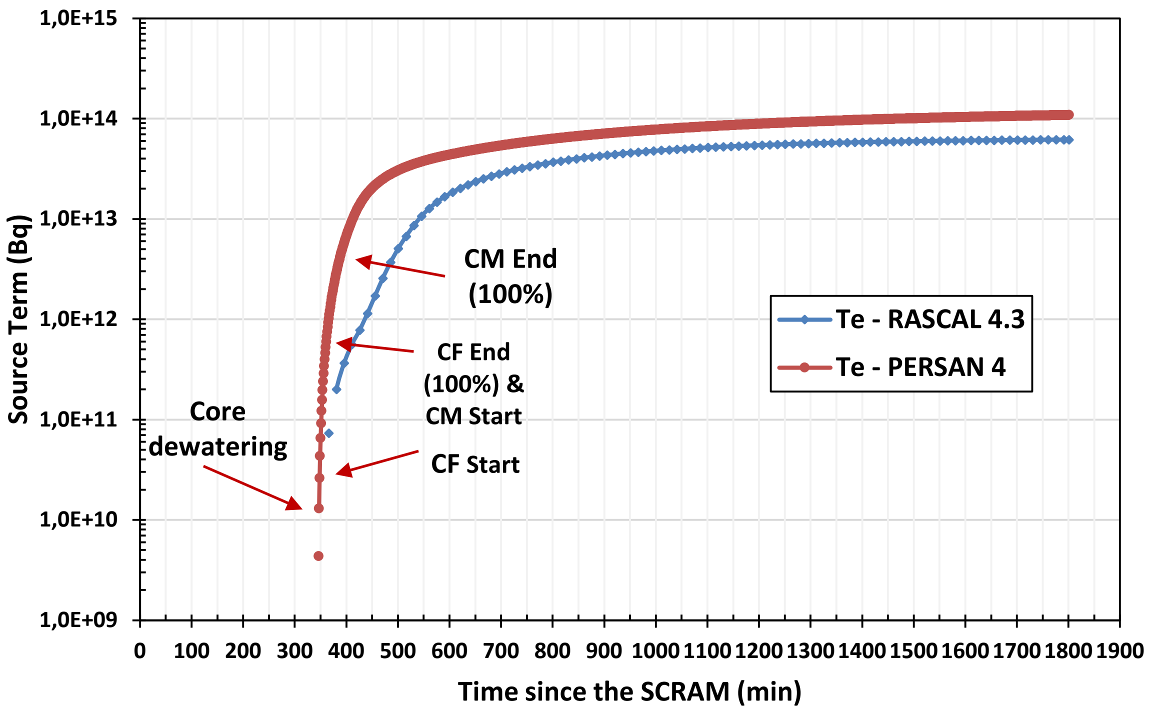
Results – ST#2 intercomparison

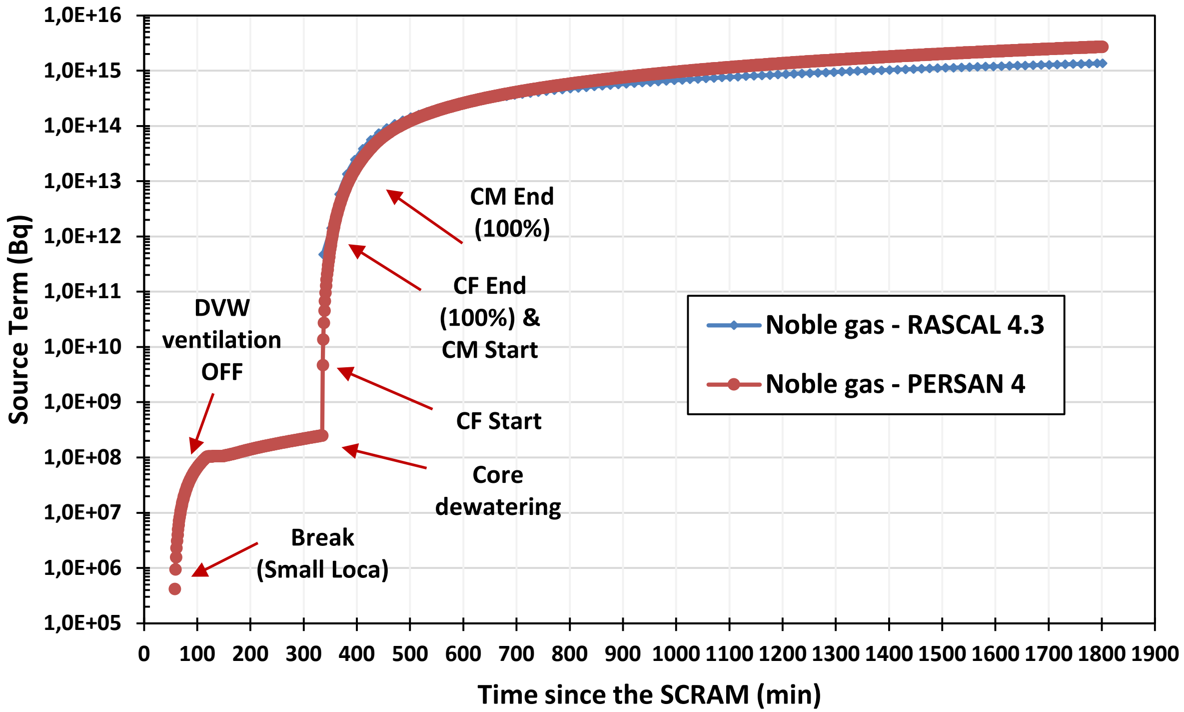
- ST#2 results (evaluation of the ST 24 hours after the RT with information available at 12h00)
  - IRSN data: pressure increase in the RB since 08:27 (LOCA); CSS OFF; Containment pressure 1.2 bar





Results – ST#2 intercomparison





- PERSAN slightly overestimates (i.e., about a factor 1.25 ÷ 2) the ST wrt RASCAL.

Total Release

	PERSAN 4	RASCAL 4.3	VAR (%)
Noble Gas	2.70E+15	1.35E+15	99.26
Cesium	2.27E+13	1.81E+13	25.33
Iodine	3.67E+14	2.20E+14	66.55
Tellurium	1.09E+14	6.17E+13	76.44

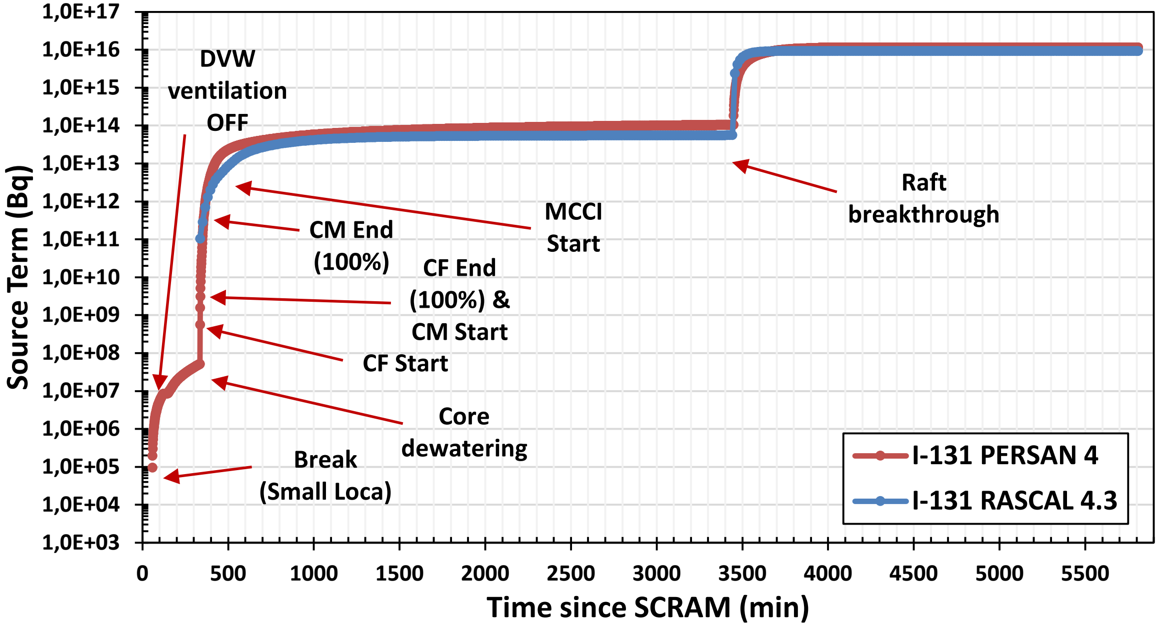
Results – ST#2 intercomparison

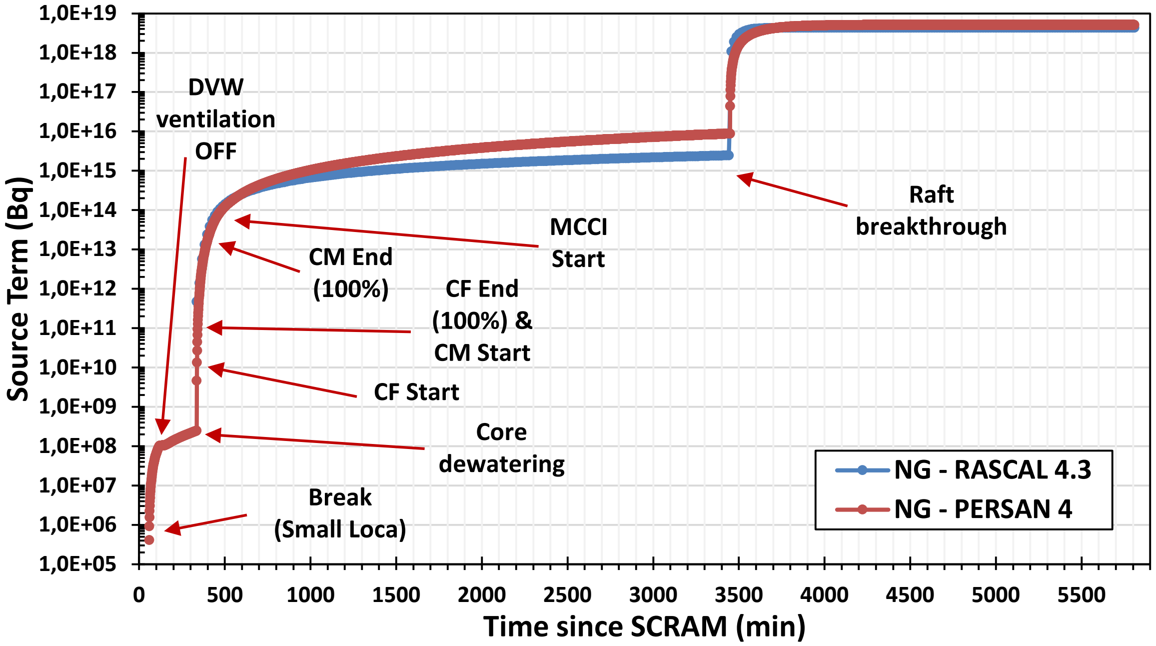
- The radionuclide intercomparison reveals a general good agreement;
- Differences were found for some actinides (Am-241, Pu-238, Pu-239) probably because the two codes have different MOX and UOX core inventories;
- Some other nuclides (Mo-99, Pm-147, Rh-105, Ru-106, Tc-99m) show also non negligible differences;
- Kr-83m and Nb-95m are not present in the PERSAN output.

Nuclide	RASCAL 4.3	PERSAN 4	PERSAN /RASCAL ratio	Nuclide	RASCAL 4.3	PERSAN 4	PERSAN /RASCAL ratio
Am-241	2.21E+05	1.28E+08	580.2	Pu-241	8.88E+10	6.50E+10	0.7
Ba-139	1.28E+11	7.14E+11	5.6	Rb-86	1.23E+11	1.04E+11	0.8
Ba-140	2.57E+13	7.45E+13	2.9	Rb-88	1.09E+13	1.38E+13	1.3
Ce-141	1.17E+12	2.91E+12	2.5	Rh-103m	7.73E+11	2.63E+13	34.0
Ce-143	8.08E+11	2.04E+12	2.5	Rh-105	4.41E+11	1.77E+13	40.1
Ce-144*	9.48E+11	2.16E+12	2.3	Ru-103	7.75E+11	2.58E+13	33.3
Cm-242	2.93E+10	2.76E+10	0.9	Ru-105	8.84E+10	3.13E+12	35.4
Cs-134	8.66E+12	1.02E+13	1.2	Ru-106*	2.17E+11	8.87E+12	40.8
Cs-136	3.43E+12	4.77E+12	1.4	Sb-127	3.00E+12	5.04E+12	1.7
Cs-137*	5.99E+12	7.68E+12	1.3	Sb-129	1.72E+12	2.85E+12	1.7
Cs-138	1.59E+09	1.15E+10	7.3	Sr-89	1.33E+13	2.56E+13	1.9
I-131	5.30E+13	9.28E+13	1.8	Sr-90	1.03E+12	1.81E+12	1.7
I-132	6.33E+13	9.64E+13	1.5	Sr-91	6.54E+12	1.28E+13	2.0
I-133	7.33E+13	1.28E+14	1.7	Sr-92	9.37E+11	2.23E+12	2.4
I-134	1.00E+11	7.16E+11	7.1	Tc-99m	7.29E+11	1.16E+14	159.4
I-135	3.06E+13	4.89E+13	1.6	Te-127	3.51E+12	5.46E+12	1.6
Kr-83m	6.39E+11	-	-	Te-127m	5.53E+11	7.81E+11	1.4
Kr-85	4.36E+12	2.40E+09	0.0	Te-129	1.53E+12	6.31E+12	4.1
Kr-85m	1.26E+13	1.83E+13	1.4	Te-129m	2.32E+12	4.67E+12	2.0
Kr-87	6.32E+11	6.07E+11	1.0	Te-131	1.24E+12	1.51E+12	1.2
Kr-88	1.27E+13	1.55E+13	1.2	Te-131m	5.52E+12	7.10E+12	1.3
La-140	3.46E+12	1.82E+13	5.3	Te-132	4.70E+13	8.28E+13	1.8
La-141	1.33E+11	1.38E+12	10.4	Xe-131m	7.07E+12	1.02E+13	1.4
La-142	8.07E+09	1.23E+11	15.2	Xe-133	9.99E+14	2.00E+15	2.0
Mo-99	7.74E+11	1.16E+14	150.4	Xe-133m	2.75E+13	6.05E+13	2.2
Nb-95	1.18E+12	5.94E+12	5.0	Xe-135	2.73E+14	5.60E+14	2.0
Nb-95m	8.44E+08	-	-	Xe-135m	1.70E+13	2.96E+13	1.7
Nb-97	3.64E+10	1.42E+12	39.1	Xe-138	2.35E+05	3.03E+06	12.9
Nd-147	4.42E+11	3.81E+11	0.9	Y-90	1.20E+11	1.80E+11	1.5
Np-239	1.29E+13	3.68E+13	2.9	Y-91	8.54E+11	8.12E+11	1.0
Pm-147	1.87E+08	1.41E+13	75284.7	Y-91m	3.13E+12	6.34E+12	2.0
Pr-143	1.03E+12	2.71E+12	2.6	Y-92	6.72E+11	1.44E+12	2.1
Pr-144	9.45E+11	2.13E+12	2.3	Y-93	2.70E+11	3.90E+11	1.4
Pu-238	3.70E+05	1.50E+09	4062.5	Zr-95	1.16E+12	9.93E+11	0.9
Pu-239	6.30E+05	1.45E+08	229.6	Zr-97*	6.41E+11	5.78E+11	0.9

Results – ST#3 intercomparison

- ST#3 results (evaluation of the ST four days after the RT with information available at 16h00)
  - IRSN data: 100% Core melt; CSS OFF; ventilation in operation;





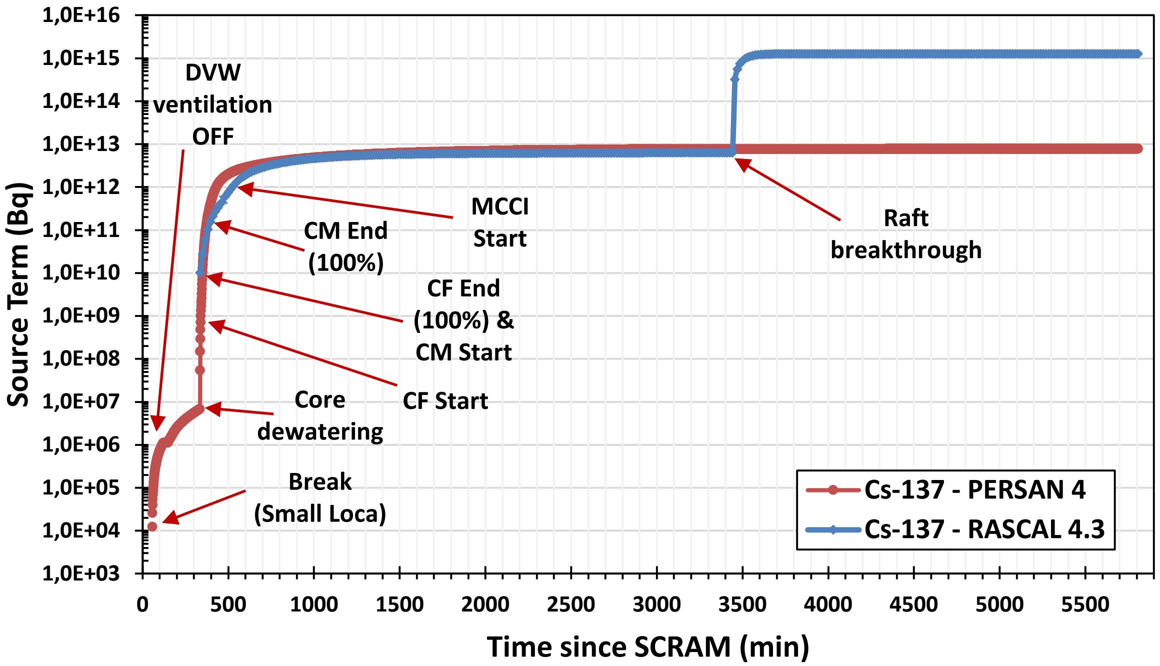
- In RASCAL the raft breakthrough event was modelled with a containment total failure, while the chemistry of the MCCI cannot be modelled;
- In PERSAN the leak rate of the raft breakthrough was set to 1000% vol/d, half the value of RASCAL (100% vol/h);

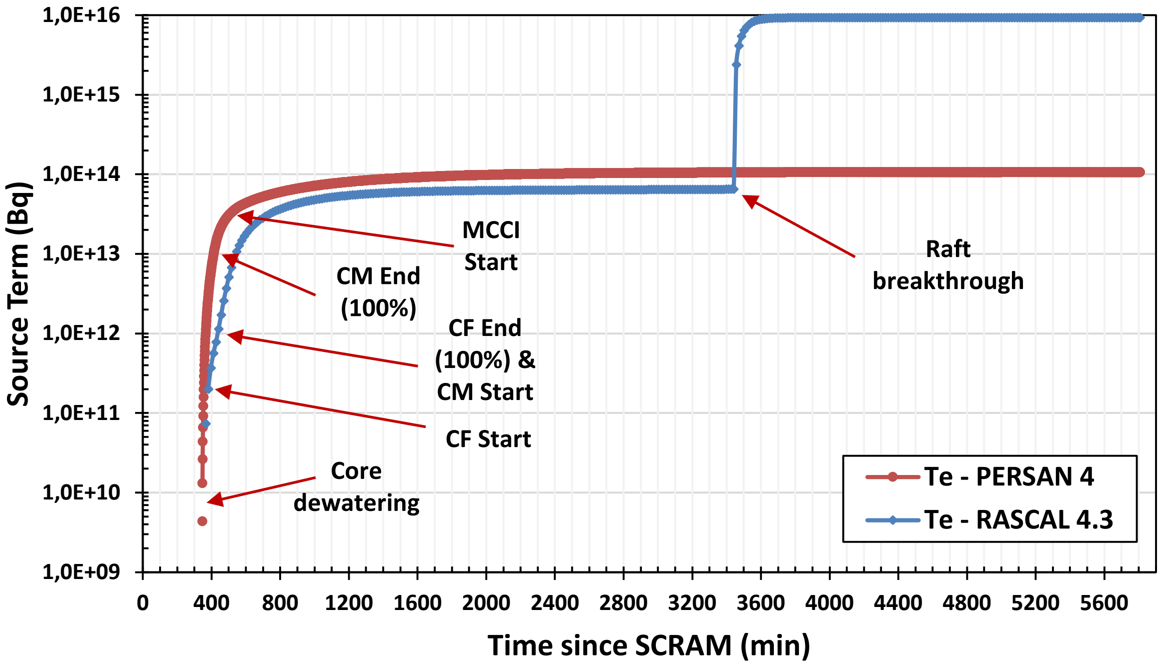
Results – ST#3 intercomparison

- Cs-137 and Te dynamics and total release can not be compared because only PERSAN correctly assumes a filtering efficiency for aerosol by terrain at raft breakthrough;
- A containment total failure of RASCAL is always of the unfiltered type;

Total Release			
	PERSAN	RASCAL	VAR (%)
Noble gas	5.19E+18	4.33E+18	19.86
Cesium	2.27E+13	3.76E+15	-99.40
Iodine	1.58E+16	2.00E+16	-21.08
Tellurium	1.06E+14	1.85E+16	-99.43

In RASCAL no aerosol ground filtering option!





Results – ST#3 intercomparison

- The radionuclide intercomparison reveals that the non aereosol nuclides (I, NG) are in good agreement;
- RASCAL semi-volatile and volatile aerosol (i.e., Cs, Te, Mo, Rb, Se, Rh, Tc, Ba, La, Ru, Sb, Np) results are roughly two orders of magnitude higher than those of PERSAN;
- The difference is again due to the lack of aerosol filtration for raft breakthrough events in RASCAL

Nuclide	RASCAL 4.3	PERSAN 4	PERSAN /RASCAL ratio	Nuclide	RASCAL 4.3	PERSAN 4	PERSAN /RASCAL ratio
Am-241	2.13E+08	1.26E+08	0.59	Pu-241	2.01E+13	6.38E+10	0.00
Ba-139	1.28E+11	6.99E+11	5.46	Rb-86	2.43E+13	1.04E+11	0.00
Ba-140	5.21E+15	7.26E+13	0.01	Rb-88	1.22E+13	1.48E+13	1.21
Ce-141	2.54E+14	2.85E+12	0.01	Rh-103m	1.58E+14	2.63E+13	0.17
Ce-143	7.23E+13	1.90E+12	0.03	Rh-105	3.96E+13	1.69E+13	0.43
Ce-144*	2.14E+14	2.12E+12	0.01	Ru-103	1.58E+14	2.58E+13	0.16
Cm-242	6.62E+12	2.71E+10	0.00	Ru-105	1.02E+11	2.93E+12	28.85
Cs-134	1.83E+15	1.02E+13	0.01	Ru-106*	4.55E+13	8.89E+12	0.20
Cs-136	6.59E+14	4.76E+12	0.01	Sb-127	4.83E+14	4.83E+12	0.01
Cs-137*	1.27E+15	7.72E+12	0.01	Sb-129	1.96E+12	2.63E+12	1.34
Cs-138	1.59E+09	1.15E+10	7.25	Sr-89	2.91E+15	2.50E+13	0.01
I-131	9.28E+15	1.16E+16	1.25	Sr-90	2.32E+14	1.78E+12	0.01
I-132	7.34E+15	9.42E+13	0.01	Sr-91	6.02E+13	1.16E+13	0.19
I-133	3.32E+15	4.04E+15	1.22	Sr-92	9.39E+11	2.12E+12	2.25
I-134	1.00E+11	7.12E+11	7.11	Tc-99m	9.81E+13	1.13E+14	1.15
I-135	7.86E+13	9.57E+13	1.22	Te-127	6.55E+14	5.34E+12	0.01
Kr-83m	6.39E+11	-	-	Te-127m	1.23E+14	7.84E+11	0.01
Kr-85	2.22E+16	7.08E+12	0.00	Te-129	3.27E+14	6.07E+12	0.02
Kr-85m	9.27E+13	9.04E+13	0.98	Te-129m	5.02E+14	4.67E+12	0.01
Kr-87	6.32E+11	6.28E+11	0.99	Te-131	9.97E+13	1.44E+12	0.01
Kr-88	1.39E+13	1.80E+13	1.29	Te-131m	4.43E+14	6.76E+12	0.02
La-140	3.26E+15	2.01E+13	0.01	Te-132	7.11E+15	8.09E+13	0.01
La-141	1.42E+11	1.28E+12	9.05	Xe-131m	3.27E+16	3.00E+16	0.92
La-142	8.07E+09	1.20E+11	14.83	Xe-133	4.10E+18	4.88E+18	1.19
Mo-99	1.02E+14	1.13E+14	1.11	Xe-133m	8.22E+16	1.25E+17	1.51
Nb-95	2.68E+14	5.81E+12	0.02	Xe-135	9.09E+16	1.45E+17	1.60
Nb-95m	6.79E+11	-	-	Xe-135m	4.96E+15	6.71E+15	1.35
Nb-97	1.36E+12	1.36E+12	1.00	Xe-138	2.35E+05	3.03E+06	12.91
Nd-147	8.96E+13	3.71E+11	0.00	Y-90	1.05E+14	2.25E+11	0.00
Np-239	1.70E+15	3.49E+13	0.02	Y-91	2.05E+14	8.02E+11	0.00
Pm-147	1.69E+11	1.38E+13	81.80	Y-91m	3.71E+13	5.57E+12	0.15
Pr-143	2.25E+14	2.65E+12	0.01	Y-92	7.68E+11	1.25E+12	1.62
Pr-144	2.14E+14	2.09E+12	0.01	Y-93	3.04E+12	3.53E+11	0.12
Pu-238	3.48E+08	1.47E+09	4.24	Zr-95	2.58E+14	9.73E+11	0.00
Pu-239	4.72E+08	1.42E+08	0.30	Zr-97*	2.38E+13	5.28E+11	0.02

Conclusions

- An intercomparison of the ST results produced by PERSAN 4 and RASCAL 4.3 has been made;
- The analysis was performed using the SA proposed by IRSN for the Excercise 2 of the FASTNET Project;
- The intercomparison for #ST1 was not possible because RASCAL does not foresee a release into the atmosphere before a dewarering event;
- The intercomparison for #ST2 shows a good agreement;
- PERSAN can be considered more accurate because it models the effect of many more accidental phenomena (containment pressure, ventilation systems, filtering); it considers the contribution to the ST from the auxiliary buildings, and is capable of differentiating between iodine chemical forms;
- The intercomparison for #ST3 revealed that RASCAL can model a raft breakthrough with a total failure event but it does not provide the possibility of ground filtering and its associated aerosol reduction in the ST.

Thank you for your attention!

Any questions?