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FISSION PRODUCTS TRANSPORT AND CHEMISTRY INTO CANDU TYPE REACTOR DURING A SEVERE ACCIDENT

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Abstract. *The paper is intended to analyse the distribution of the fission products (FPs) in CANDU Primary Heat Transport (PHT) and CANDU Containment Systems, including chemistry, by using the ASTEC code. The source term of FPs, introduced into the PHT, was estimated by ORIGEN code. The data related to the nodes definitions, temperatures and pressure conditions were chosen as possible as real data from CANDU loss of coolant accident sequence (CATHENA code results). The FPs distribution and chemistry, in different nodes of the PHT and CANDU Containment, were obtained by a coupled calculation SOPHAEROS-CPA-IODE. All modules are integrated in SA code ASTEC.*

Keywords: severe accidents, fission products, safety, CANDU, transport

1. Introduction

The most important result of Severe Accident (SA) analysis is the source term (the radioactive sources released into the environment). The different fission products (FPs) are released from the fuel bundles through the clad rupture, transported by the coolant and deposited into different regions of the Primary Heat Transport (PHT) and containment system. Different hosts (aerosols, gas, liquids) are involved in transport and deposition phenomena. The chemistry process is taken into account in order to obtain a realistic model.

The ASTEC code is dedicated for SA analysis of PWR reactors and involves a lot of models and methods. Some of them are presented in [1, 2]. The use of ASTEC at CANDU type reactors introduces many difficulties especially for the core degradation phenomena [3]. A simplified calculation was presented in [4]. In this paper the problem of the FPs transport (during SA) between fuel bundles and containment is analysed by a coupled calculation SOPHAEROS-CPA-IODE. The FPs and chemical species distributions, in different PHT nodes, containment regions and hosts, are obtained.

2. Te definition of the problem

For PHT System only ½ of the circuit (see figure 1) was simulated: 190 horizontal fuel channels connected to 190 horizontal out-feeders, then through vertical feeders to the outlet-header; the circuit continues from the outlet-header with a riser and then with the steam generator and a pump. Two identical steam

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generators loops are present. The containment model consists of 12 rooms connected between by 14 links (see figure 1).

The data related to the nodes' definitions, temperatures and pressure conditions were chosen as possible as actual data from CANDU NPP loss of coolant accident sequence. Temperature and pressure conditions in the time of the accident were calculated by CATHENA code and the source term of FPs introduced into the PHT was estimated by ORIGEN code.

The inventory of FPs in the CANDU core (loaded with fuel bundles with average discharge burn-up) is presented in Table 1. A fraction of the inventory (specific for each isotope) is released from the fuel after the clad rupture. The released inventory is an input given data.

Generally, in integral ASTEC calculation the released inventory is calculated automatically by ELSA module, but DIVA-ELSA module is not appropriate for CANDU geometry.

The releasing fractions are, generally, literature data and have important uncertainties.

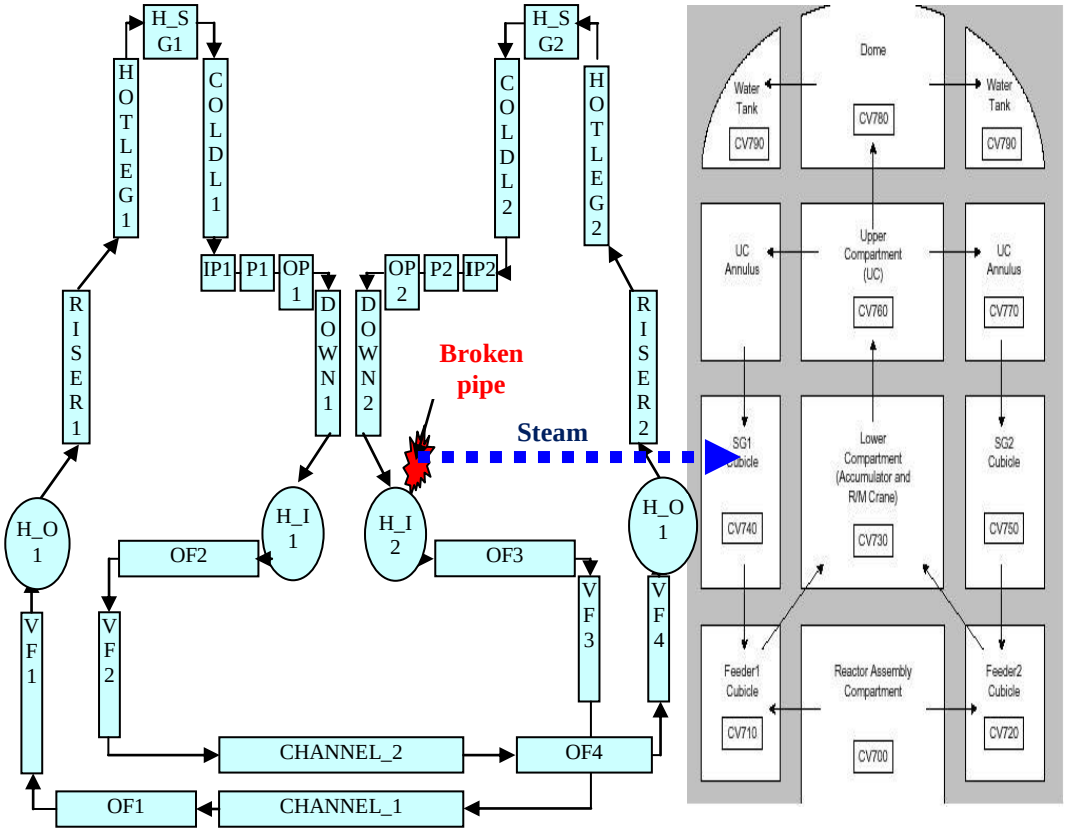

Fig. 1. Geometrical model for SOPHAEROS-CPA-IODE calculation.

3. Results and Discussions

In Table 1 the FPs inventory, calculated by ORIGEN code, the releasing fractions (literature data and our hypothesis) and released masses into PHT are presented.

Table 1. FPs Release into CANDU PHT

Isotope	Core inventory [kg]	Releasing fractions	Released mass [kg]	Isotope	Core inventory [kg]	Releasing fractions	Released mass [kg]
Kr	7.33	0.50	0.91992	I	11.90	0.20	0.59738
Rb	6.54	0.20	0.32831	Xe	81.40	0.50	10.216
Sr	28.00	0.05	0.35140	Cs	28.00	0.20	1.4056
Y	11.90	0.05	0.14935	Ba	36.60	0.05	0.45933
Zr	61.60	0.01	0.15462	La	22.00	0.05	0.27610
Mo	43.40	0.05	0.54467	Ce	58.70	0.05	0.73669
Tc	8.64	0.01	0.02160	Pr	14.30	0.01	0.03589
Ru	35.80	0.05	0.44929	Nd	38.70	0.01	0.09714
Pd	3.96	0.01	0.00994	Pm	3.27	0.01	0.008175
Te	13.00	0.20	0.65260	Sm	5.25	0.01	0.013125

The total amount of FPs released into CANDU PHT is supposed at 8.2 kg. The releasing starting time was chosen at 150 s, after the LOCA initiating, in accordance with the temperature conditions on cladding, calculated by CATHENA. The duration of the releasing was supposed 5s, in accordance with literature data and our hypotehesis. The releasing fractions are very dependent on the isotope's class: volatile, low-volatile or non-volatile.

For each isotope the transport and deposition into PHT nodes and Containment rooms, for different host were calculated. Illustrative, in Table 2 the deposition, condensation on walls or aerosols, and the injection from PHT to containment system as vapors or aerosols are presented as percentage from inlet mass of each FP.

For the source term evaluation the following FPs are very important: Iodine, Cesium, Strontium. The balance for iodine and associated species in PHT CANDU is presented in Table 3, for t=900 s after the initiating accident time. The distribution of total iodine in the nodes of PHT is presented in figure 2.

The total iodine (including associated species) is distributed into different containment's rooms and different hosts. The evolution of the distribution in main rooms and hosts is presented in figure 3.

Table 1. FPs condensation, deposition and injection in containment

Isotope	Condensed on walls [%]	Condensed on deposited aerosols [%]	Deposited aerosols [%]	Total deposited [%]	Out_1 (Vapour) [%]	Out_2 (Aerosols) [%]	Total out [%]
I	68.49%	27.31%	0.00%	95.79%	0.00%	4.10%	4.10%
Cs	30.21%	39.93%	0.00%	70.14%	6.30%	23.56%	29.86%
Te	66.44%	29.05%	0.00%	95.49%	0.18%	4.31%	4.49%
Kr	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	100.00%
Xe	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	100.00%
Rb	11.98%	0.38%	0.00%	12.36%	39.27%	48.36%	87.64%
Sr	59.96%	34.78%	0.00%	94.74%	0.05%	5.21%	5.26%
Mo	48.53%	48.19%	0.00%	96.72%	0.00%	3.28%	3.28%
Ru	53.11%	43.55%	0.00%	96.66%	0.00%	3.34%	3.34%
Ba	57.21%	37.22%	0.00%	94.43%	0.00%	5.57%	5.57%
Nd	0.00%	0.00%	99.66%	0.00%	0.00%	0.00%	0.00%
Y	0.00%	0.00%	99.67%	0.00%	0.33%	0.00%	0.33%
Zr	0.00%	0.00%	99.66%	0.00%	0.34%	0.00%	0.34%
Tc	0.00%	0.00%	99.68%	0.00%	0.32%	0.00%	0.32%
Pd	0.00%	0.00%	99.60%	0.00%	0.30%	0.00%	0.30%
La	0.00%	0.00%	99.67%	0.00%	0.33%	0.00%	0.33%
Ce	0.00%	0.00%	99.67%	0.00%	0.33%	0.00%	0.33%
Pr	0.00%	0.00%	99.67%	0.00%	0.33%	0.00%	0.33%
Pm	0.00%	0.00%	99.63%	0.00%	0.37%	0.00%	0.37%
Sm	0.00%	0.00%	99.62%	0.00%	0.30%	0.00%	0.30%

The results are obtained for each isotope. For simplicity only iodine details are presented. It can be seen that the most important deposition of iodine is in the node 1 (fuel channels), 72%, due to the great surface for deposition and the number of channels. At the same time, the iodine chemistry is very important. The main iodine quantity of injection from PHT into containment is in the species: Cs_2I_2 and CsI.

Table 1. Iodine balance for PHT transport, deposition and chemistry

Species	Inlet	mass [g]
Iode		**597.38**
I	Condensed on Walls	409.12
	Condensed on Deposited Aerosols	163.48
	Outlet Number 1 (Vapour)	0.29
	Outlet Number 1 (Aerosols)	24.48
BaI_2	Condensed on Walls	28.67
	Condensed on Deposited Aerosols	7.98-06
	Outlet Number 1 (Aerosols)	4.52
Cs_2I_2	Condensed on Deposited Aerosols	287.6
	Outlet Number 1 (Aerosols)	43.09
CsI	Condensed on Walls	671.14
	Condensed on Deposited Aerosols	43.29
	Outlet Number 1 (Aerosols)	6.46
I_2Sr	Condensed on Walls	1.27
IRb	Condensed on Walls	97.73
	Condensed on Deposited Aerosols	3.12
	Outlet Number 1 (Aerosols)	0.47
ISr	Condensed on Walls	1.94

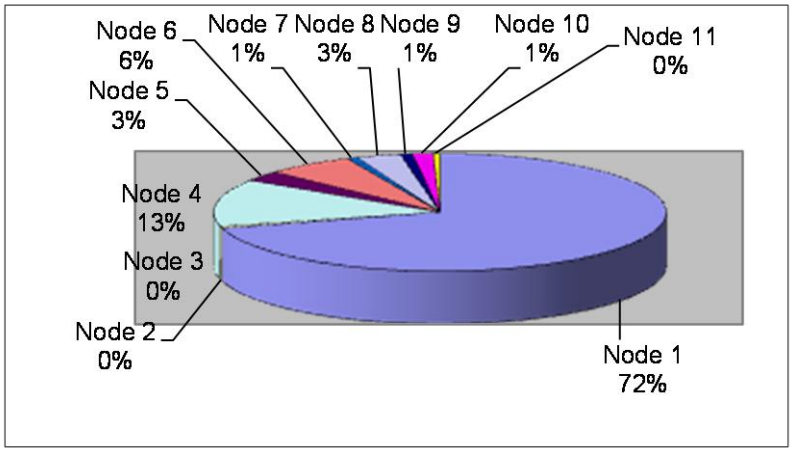

Fig. 2. Deposited fractions for different PHT's nodes (node, % from total deposition).

In the containment the iodine is accumulated in CV770 room (see figure 1) in the water host. Moreover, if we suppose that Cesium is not present (arbitrary hypothesis) at t = 5000 s, most Iodine (**524.36** out of **597.38** g) was present in the sump of the CV770 compartment, as $\mathbf{I^-}$, due to the wall wash-out.

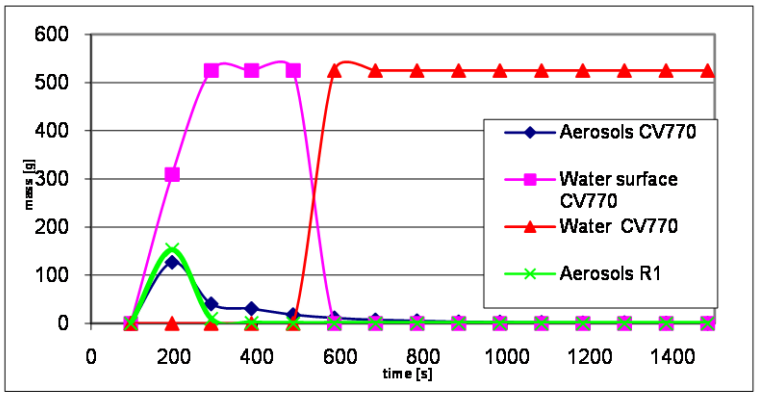

Fig. 3. Iodine evolution in the containment rooms and different hosts.

Conclusions

(1) A coupled calculation with the ASTEC code modules SOPHAEROS-CPA-IODE was performed. The results proof the adaptability of the models and these modules to CANDU type reactors. Excepting the core degradation phenomena and corium relocation, the code can evaluate the source term, if appropriate initial and boundary conditions are introduced.
(2) The distributions of the FPs in the PHT and containment systems are one of the most important calculations in the severe accident analysis. The depositions in the different parts of the reactor drastically influence the source term. In case of CANDU our analyze shows that (excepting Xe, Kr) more than 70% of the released masses are deposited into PHT. At the same time for important FPs source term the main part of the PHT transfer to containment is deposited into the sump water.
(3) The results confirm the expectation from the point of view of normal physical behavior. However, taking into account the uncertainties associated with the input data and models, experimental efforts are needed. The used models can be improved, but the critical point, for CANDU type reactor, is the scarcity of the experimental data.

R E F E R E N C E S

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