FISSION PRODUCT SOURCE FROM IGNALINA NPP IN CASE OF LOSS-OF-COOLANT ACCIDENTS

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The release of radioactive materials to the environment is of special importance in the case of any accident at Nuclear Power Plants (NPP). The integrated analysis of thermal-hydraulic parameters behavior and radioactive fission products (FP) transport and deposition in the compartments play an important role in the evaluation of FP release to the environment and determines the irradiation dozes of personnel and public.

In this report the transport and the deposition of radioactive material in the Ignalina NPP unit 1 compartments as well as the FP source term to the environment in the case of design basis loss-of-coolant accidents are discussed. The calculation models for the evaluation of FP transport and deposition as well as the results of performed calculations of several accidents at Ignalina NPP are presented.

1 Introduction

Ignalina NPP is the only nuclear power plant in Lithuania. This plant is equipped with two RBMK-1500 type reactors with nominal thermal capacity of 4800 MW each. Should be mentioned that after Chernobyl accident the allowed power was reduced to 4200 MW. Detailed description of the Ignalina NPP may be found in [1].

The main barriers preventing radioactive material release to the environment are: fuel pellet; fuel element cladding; main circulation circuit (MCC) and building structures. During normal operation the radioactive FP are accumulated in the gap between fuel pellet and cladding. If the cladding is leaktight the FP do not get into the MCC. If the cladding fails the fission products leak from the gap between fuel and cladding to the MCC but if the fuel is not overheated then the main part of FP remains in the fuel pellet. In the case of MCC piping rupture the FP together with the contaminated steam-gas mixture enter the compartments and may be transported there and further to the environment through the structural leaks of building or through the overpressure protection devices.

At Ignalina NPP there is a special system of reiforced-leaktigh compartments performing functions of containment. This system is called Accident Localization System (ALS) and could be considered as pressure suppression type containment. There are 10 pressure suppression pools designed to condense the accident-generated steam and suppress the peak pressure and retain the radioactive FP. The peculiarity of Ignalina NPP is that some part of the MCC as well as steam-lines are located outside this system [1]. Complicated geometry of Ignalina NPP compartments and the circuit cause the different FP release paths and conditions for different accidents.

If the crack in fuel cladding appears the main barrier preventing the radioactive FP release is lost and the coolant in the MCC becomes radioactive.

In the case of MCC piping break the next barrier shielding radioactive products is lost and the radioactive steam-gas mixture can reach the environment due to the leaks in building structures that are present in case of normal operation or/and in case of releases inside or outside ALS compartments.

2 Fission products accumulation in the fuel-cladding gap

The isotopic composition of the fuel in the Ignalina NPP reactor is presented [2] where is also presented the amount of FP accumulated in the fuel-cladding gap of leak-tight fuel elements. The amount of FP accumulated in the fuel-cladding gap of the leaking fuel elements is presented in [3].

The first barrier preventing the radioactive materials release is the fuel pellet. The main part of FP remains in the fuel pellet but some part of gaseous and volatile FP enters the fuel-cladding gap. The fuel temperature is the main factor determining the FP release from fuel pellet. The question of the highest interest is the accumulation of the iodine and cesium.

Ignalina NPP may operate with the certain level of coolant activity, i.e. may have the certain amount of failed fuel claddings [4, 5]. According to the regulations [4] the permissible level of coolant activity defined as the number of the failed fuel claddings comprises 1 % of fuel elements with gas ingress and 0.1 % of fuel-elements with moisture ingress. Considering that Ignalina NPP reactor RBMK-1500 consists of 1661 fuel channel the number of failed fuel elements comprises 598 fuel elements with gas ingress and 60 fuel elements with moisture ingress.

In the performed analyses assumed that the failed fuel elements are distributed on the both halves of the reactor to comply with the highest permissible activity level on the safe operation limit ($2 \cdot 10^{-5}$ Ci/kg of ^{131}I).

3 Fission products release to the MCC

The efficiency of the reactor cooling influences the FP release to the MCC. If the reactor was reliably cooled the FP would be released only from the fuel-cladding gap of the fuel elements that are failed prior to piping rupture. Such situation is characteristic for the design basis accidents when the reactor cooling system performs its design functions. If during the accident the fuel overheats then the additional failures of fuel claddings or even the fuel melting could occur. In such case FP would be released both from the fuel-cladding gap and the fuel matrix.

In the analysis conservatively assumed that all the FP accumulated in the fuel-cladding gap of the fuel element failed prior to accident enters the MCC right after the accident start. In the analysis the time of the FP release to MCC should be evaluated if during the accident the additional fuel elements fail or fuel starts to melt.

4 Fission products release to the accident compartment

In case of loss-of-coolant accident (LOCA) the contaminated steam-water mixture is released to the accident compartment. Considering that both halves of MCC interconnects through the steam-lines joints then the FP from one to another halves of MCC may get only in case of steam-lines rupture. If rupture occurs in MCC then only the halve of the total number of fuel elements failed prior to accident (0.55 % of all the fuel elements) should be evaluated, i.e. it is assumed that in the failed MCC loop there are 299 fuel elements with gas ingress and 30 fuel elements with moisture ingress.

In the case of steam-line rupture the FP would be released from both halves of the reactor and the total amount of FP accumulated in the fuel-cladding gap of failed fuel elements (1.1 % of all the fuel elements) should be considered.

As the coefficient of the iodine and cesium isotopes distribution between the water and steam during normal operation of NPP comprises 10^{-3} – 10^{-4} [6] then the steam entering the steam-lines is clean comparatively to coolant in MCC. In case of MCC piping rupture is assumed that all FP released to the coolant of failed MCC loop enter the accident compartment. In the initial stage of the accident involving steam-line rupture only the steam and the noble gases would get to the steam-lines and isotopes of iodine and cesium would comprise comparatively small part. But in the case of water level increase in drum separator (DS) the steam separation gets worse and the two-phase mixture may get into the steam-lines. In such case the transport of iodine and cesium isotopes from the MCC to the steam-lines by the water droplets should be considered. Because to model the transport of FP through the steam-lines in detail is very difficult the humidity of the steam is considered and in such way the water mass released through the steam-lines to the accident compartment is defined. In the analysis of breaks in the steam-lines system the decrease of FP concentration in the coolant due to emergency core cooling system (ECCS) water supply should be considered.

As it was shown in [7, 8] no less than 95 % of iodine released to the compartment from the cooling circuit is of cesium iodide chemical form and no more than 5 % is elemental gaseous form.

5 Transport of radioactive fission products in the compartments

After MCC piping rupture one of the last barriers preventing from FP release to the environment is lost and the radioactive coolant enters the compartment and further may be transported through the neighboring compartments and may get into the environment. The detailed description of the possible release paths to the environment for fission products is presented in Ignalina NPP PSA level 2 study. Figure 1 presents the subdivision of Ignalina NPP compartments to FP confinement zones depending on the possible release paths. Zone 1 includes reinforced-leaktight compartments of ALS, Zone 2 – group distribution header (GDH) and lower water piping compartments, Zone 3 – reactor cavity. The zones 4 and 5 are located outside the ALS, steamlines, feedwater lines and other auxiliary systems are located there. These compartments are not reinforced and the released contaminated coolant could leak to the environment.

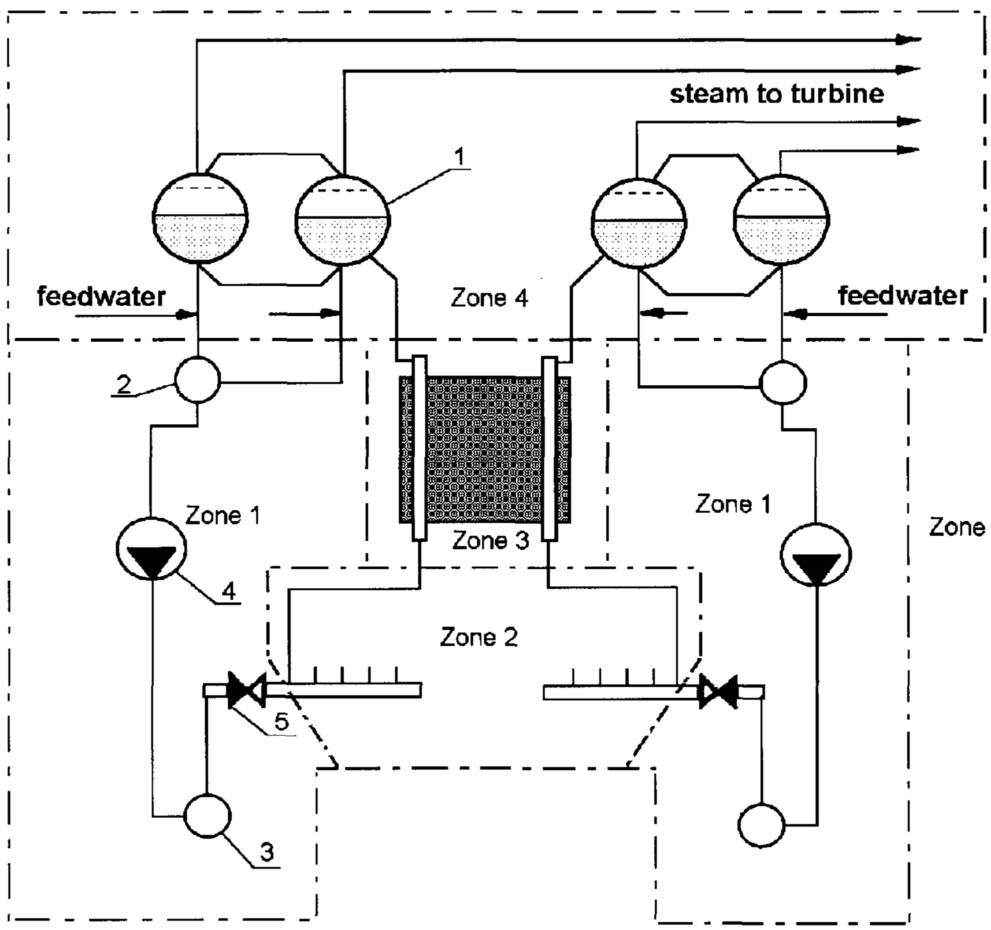

Figure 1: Ignalina NPP confinement zones

1 - drum separator; 2 - suction header; 3 - pressure header; 4 - main circulation pump; 5 - check valve

The transport of radioactive fission products in the compartments depends on the FP concentration and the excess pressure in the reference compartment. The transport and the deposition of the FP in the compartments is calculated employing code CONTAIN [9]. Employing this code it is possible to perform the integral evaluation of the thermal-hydraulic parameters in the compartments and the radioactive FP release to the environment.

6 Fuel cladding integrity monitoring

At Ignalina NPP there is a special system for fuel cladding integrity monitoring (FCIM). It is designed to monitor the radioactivity level in the coolant. Detailed description of FCIM system is presented in [1, 3]. FCIM system consists of two structurally independent but functionally related control channels:

- Channel group FCIM;
- Individual channel FCIM.

The operation of this system gives the possibility to detect failed fuel element in 10 minutes. The signal about activity increase in the circuit is provided in main control room. As the fuel assemblies from RBMK core may be changed online the assumed number of fuel elements with large leaks that are present in the core (60 fuel elements) is very conservative.

7 Results of the performed analysis

The calculations of the radioactive materials release to the Ignalina NPP compartments were performed in the frames of SAR project [3] as well as other projects [10 - 12]. The calculations performed only for the design basis accidents – pressure header (PH) rupture; downcomer rupture in DS compartment; feedwater pipe rupture in technological corridor; steam-line rupture in technological corridor; steam-line rupture in turbine hall. In this chapter the calculation results of each mentioned accident are presented.

As the transport and the deposition of the radioactive materials depends on the thermal-hydraulic parameters behavior in the accident-affected compartments usually the same models of compartments are employed for the analysis of radiological parameters as for thermal-hydraulic analysis. Modern state-of-the-art codes gives the possibility for the integral analysis of the thermal-hydraulic parameters and the transport and deposition of the radioactive FP in the reference compartments. One of such codes is CONTAIN [9]. This code was employed for the calculation of the FP release to the environment in case of various hypothetical LOCAs (pressure header rupture; downcomer rupture in DS compartment; feedwater pipe rupture; steam-line rupture) at Ignalina NPP. Further the results of FP source term calculations are shortly presented.

7.1 Pressure header rupture

The ALS model for CONTAIN code developed in the frames of ALS safety case project [10]. This model consisting of 18 nodes (zones) and 82 structures was applied for the FP source term estimation in case of pressure header rupture. The initial temperature of water in the condensing pools is assumed 35 ^{0}C, the water level there – 0,95 m, i.e. the most conservative values allowed during normal operation.

According to the results of the measurements performed in 1997 the effective leak area of the ALS at Ignalina NPP unit 1 comprises: reinforced leaktight compartments – 3000 cm^2, each ALS tower 1700 cm^2. Should be mentioned that the leaks of the ALS at Ignalina NPP unit 2 presented in [2] are considerably less than leaks in unit 1.

Consequently, FP release to the environment in case of LOCA at Ignalina NPP unit 2 would be considerably lower than was calculated for ALS of unit 1. The FP from ALS through the structural leaks enter the neighboring compartments and further are taken to ventilation stack (elevation 150 m) by the ventilation systems. These systems are equipped with aerosol filters but it was neglected in the analysis.

The peculiarity of Ignalina NPP ALS is that clean air is pushed from ALS in the initial phase of the accident and further ALS is isolated from the environment [1]. The clean air release from the ALS towers to the environment is simulated by the special junctions that close after 5 minutes from the accident start. This is in agreement with the time for the flooding of release pipes section and ball type valves flow up to isolate the ALS from environment.

The calculations of the full PH rupture with the simultaneous loss of off-site power and GDH check valve failure performed in the frames of Ignalina NPP ALS safety case project [10]. It was assumed that FP from the fuel-cladding gap of maximum allowed number of fuel elements failed prior to accident enter the coolant and additionally fail claddings of fuel elements in 8 fuel channels.

Calculation results showed that in case of PH rupture 3963 Ci of ^{131}I and 35.7 Ci of ^{137}Cs in total enter the environment at elevations of 50 and 150 m [10]. Most of the radioactive FP remain scrubbed in the water of condensing pools.

7.2 Rupture of two downcomers in DS compartment

The DS compartments as well as the steam-line compartments are located outside the ALS and there is a danger that in case of simultaneous 2 downcomers rupture the radiation dozes to public could exceed the permissible level [3, 13]. Detailed description of the model and the results of thermal-hydraulic parameters as well as of the transport and deposition of FP in the compartments in case of two downcomers rupture in DS compartment are presented in [11].

For the initial stage of the accident (no more than 30 minutes) the mass and energy source from two ruptured downcomers in DS compartment calculated employing code RELAP5 [11] was applied. For the long-term reactor cooling the mass and energy source calculated on the basis of parametric analysis using the long-term reactor thermal power decrease and ECCS water supply.

The calculation of MCC parameters behavior showed that the reactor is reliably cooled, i.e. FP get into the MCC only from the fuel elements failed prior to accident. Most of the flow from the downcomer rupture is directed to the environment through the steam relief shafts at elevation of 60 m. The FP calculations were based on such assumptions:

- All isotopes of noble gases are released to the compartments and discharged to the environment;
- 5 % of iodine isotopes are transported in gaseous phase and enter the environment;
- 95 % of iodine isotopes react with cesium and form CsI which is transported by aerosols;

- All isotopes of cesium are transported by small water droplets (aerosols);
- The radioactive FP enter the compartment after 4 s from the accident start and are fully released to the compartment in 1 s.

FP release from the DS compartments to the environment almost without deposition is caused by the fact that the water released through the break is evaporated fast, pressure rises and rupture panels breaks opening the path for direct release to the environment. Panels in the accident compartment are broken in 0.35 s after the accident start [11]. These processes are very fast, temperature in the compartments is high and FP that enter the compartment are released to the environment. The water on the compartments floor start to collect only after 10 s and after 40 s water level in DS compartment comprises only 2 mm [11]. At this time the main part of FP is already released to the environment. Only a small part of FP are deposited to the pool and directed to the drainage tank.

In case of two downcomers rupture in DS compartment 9712 Ci of ^{131}I and 1104 Ci of ^{137}Cs enter the environment at 60 m elevation [11]. The parameters of FP release in the environment are presented in Table 1.

Table 1 Rupture of two downcomers in DS compartment. The parameters of FP release in the environment

Release level, m	Thermal power of release, MW	Release timing, s
0	75	200
60	6000	20

7.3 Rupture of steam-line and feedwater pipe in the compartment 507 of block D

The calculation of MCC parameters behavior showed that in the case of steam-line rupture or feedwater pipe rupture in the compartment 507 of block D the reactor is reliably cooled, i.e. FP get into the MCC only from the fuel elements failed prior to accident.

In case of steam-line rupture in the compartment 507 of block D 20252 Ci of iodine ^{131}I and 1216 Ci of ^{137}Cs enter the environment at 48 m elevation. Should be remarked that in this analysis conservatively assumed that all the FP from MCC enter the steamlines and further are released to accident compartment. Considering the influence of interface between water steam in DS to carry over of volatile FP in the piping would lower the iodine and cesium release to the environment approximately by factor of two.

According to calculation results in case of feedwater pipe rupture in the compartment 507 of block D 9464 Ci of iodine ^{131}I and 1136 Ci of ^{137}Cs enter the environment at 48 m elevation [12]. The parameters of FP release in case of feedwater pipe rupture in the compartment 507 of block D to the environment are presented in Table 2.

7.4 Steam-line rupture in the turbine hall

In this section the calculation results of the FP release to the environment in case of steam-line rupture in turbine hall, considering the ECCS water supply to the MCC, presented. The MCC parameters calculations showed that the reactor is reliably cooled, i.e. FP get into MCC only from the fuel elements failed prior to accident [12].

As it was noted before, in the simulation of the steam-line rupture should be considered that the coefficient of the volatile FP distribution between steam and water at the phase boundary in DS comprises no more than 10^{-3} [6], i.e. steam is relatively clean in comparison to MCC water.

In case of steam-line rupture the ECCS activates and supplies the pure water (not contaminated with FP) to MCC. In such way, the FP concentration in MCC gradually decreases at the same time decreasing the FP transition from MCC to steam-lines. Nevertheless, increasing water level in DS worsens the steam separation and the water droplets enter the steam-lines making the radiological situation in accident compartment worse. The total FP release to the accident compartment in case of steam-line rupture comprises of the nuclides transported by steam and water droplets that are not separated in DS.

According to RELAP5 calculation results, approximately 390 tons of water flows to the accident compartment [12]. The initial water inventory in the MCC comprises 750 tons [1] and the ECCS supplies additionally 635 tons [12]. According to these results 28 % of MCC water enter the accident compartment. In the analysis assumed that FP transported by water droplets (aerosols) enter the accident compartment in the same proportions.

According to the calculation results in case of steam-line rupture in the turbine hall 5383 Ci of ^{131}I and 628.7 Ci of ^{137}Cs enter the environment at 0, 8 and 12 m elevations [12]. The parameters of FP release in case of steam-line rupture in the turbine hall to the environment are presented in Table 2.

Table 2 The parameters of FP release in the environment in case of steam-line and feedwater pipe ruptures

Accident place	Accident type	Release level, m	Thermal power of release, MW		Release timing, s	
			Phase 1	Phase 2	Phase 1	Phase 2
Turbine hall	Steam-line rupture	0	27	5,5	7000	93000
		8	24	1,0	7000	93000
		12	33	1,8	7000	93000
Comp. 507 block D	Feedwater pipe rupture	48,5	1700	-	100	-
	Steam-line rupture	48,5	7500	-	20	-

8 Conclusions

The conservative calculations on the FP release to the environment from Ignalina NPP in case of several design basis LOCAs were performed employing code CONTAIN.

The calculation results may be further applied for the analysis of the expected public irradiation dozes.

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