Influence of the heat transfer to the building structures on the Confinement parameters in case of a 200 mm LOCA on units 3 and 4 of NPP Kozloduy with reactorsVVER-440/V230

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Abstract

The authors present a general analysis of the mass and energy balance in the VVER-440/V230 confinement structure in case of a 200 mm LOCA, based on results from CONTAIN calculations. The character of the heat transfer to the confinement building structures is analyzed and its influence on the confinement parameters is evaluated. The results show that the building structures heat consumption is comparable to that of the Spray System heat exchanger.

1. Background of the study

The evaluation of the Confinement parameters is an important element of the work for licensing units 3 and 4 of NPP Kozloduy for a Design Basis Accident 200 mm LOCA (Loss of primary coolant with equivalent rupture diameter D=200 mm). Our studies in this field [1] have shown, that the heat transfer to the building structures has a significant impact on the balance of energy even in the first minutes of the accident. This outlined the necessity of appropriate ways and means for a qualitative and quantitative evaluation of this impact.

2. A short description of the confinement system

The confinement includes all compartments, which contain primary side equipment. In the analyses every compartment is represented by its free volume and by the surrounding building structures (walls, floor, ceiling). The total architectural volume of the confinement is $\approx 14000\ m^3$, and the total free volume: $\approx 10000\ m^3$. The main compartment is the Steam Generators Box (SGB), with a free volume of $\approx 8000\ m^3$. The average thickness of walls, floors and ceilings is ≈ 1 m (from 0.6 to 1.2 m). During operation at power the confinement is isolated from the environment (equivalent diameter of the integral untightness: ≈ 65 mm).

A characteristic feature of the confinement is the set of 9 Relief Valves (flaps), which allow for the release of steam-air mixture to the environment in case of high pressure in the SGB. One valve with a flow section of $0.212\ m^2$ opens at 1.6 bar (abs). The other eight valves have a total flow section of $8.024\ m^2$ and open at 1.8 bar (abs). The Spray System (SS) has three independent channels – each with a flow rate of 200 kg/s (720 t/h).

3. Mass and energy balance in the confinement during a 200 mm LOCA

Considering the confinement, the most adverse rupture of a primary pipe of a 200 mm diameter is the rupture of a Pressurizer (PRZ) surge line [2]. The parameters of the primary coolant release in this case are summarized on Fig.1.

The temperature profile of the SGB atmosphere is presented on Fig.2. The calculation is made with the CONTAIN code under the assumption, that one SS channel was started automatically at SGB pressure of 1.2 bar and was stopped by the operator at SGB pressure of 0.9 bar.

The purpose of this study is to give a quantitative and qualitative evaluation of the impact of the heat transfer to the building structures during the initial phase of the accident.

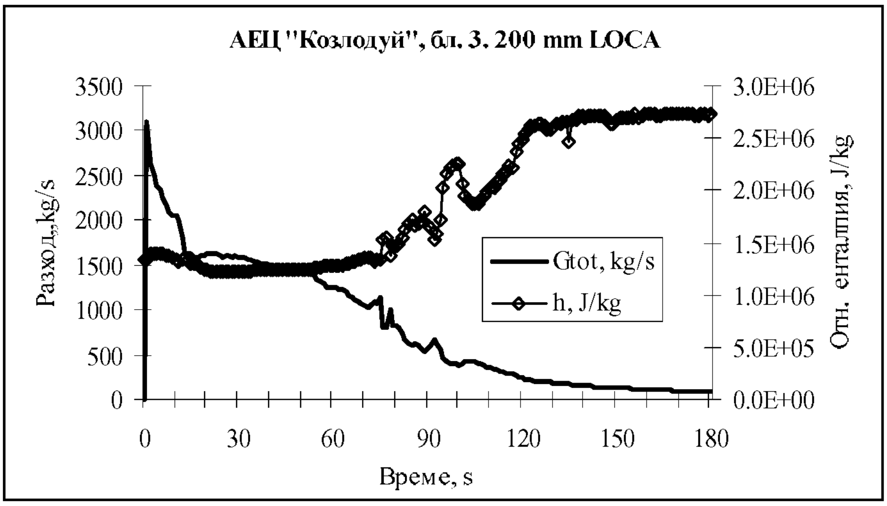

Fig. 1 Flow rate and enthalpy of the break (total – from the PRZ and from the I-ry loop) [2]

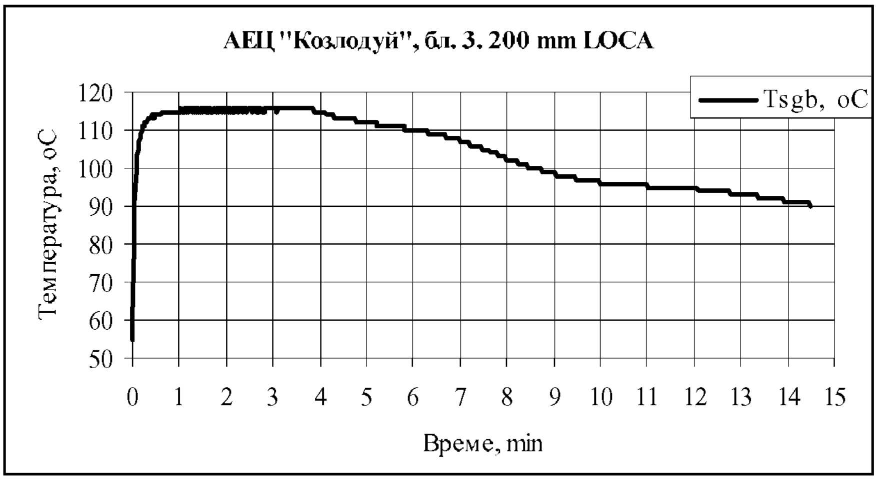

Fig. 2 Temperature profile of the SGB [3]

4. Analysis of the heat transfer to the building structures

4.1 Parameters of the heat transfer to the building structures   Table 4.1

Material	**Thickness** m	**Heat transfer factor** W/mK	**Heat capacity** J/kgK	**Density** kg/m^3
Steel	δ_s=0.004	$\lambda_s \approx$ 50.	$c_{p-s} \approx$ 460	$\rho_s \approx$ 7800
Air	$\delta_a \approx$ 0.001	$\lambda_a \approx$ 0.03	$c_{p-a} \approx$ 1000 J/kgK	$\rho_a \approx$ 1
Reinf. concrete	$\delta_{rc} \approx$ 1.	$\lambda_{sc} \approx$ 2.5	$c_{p-sc} \approx$ 760 J/kgK	$\rho_{sc} \approx$ 2420

The confinement building structures are reinforced concrete slabs with an average thickness of 1 m, plated on the inside with a 4 mm layer of carbon steel. The air gap between the steel plating and the walls varies between 0. at the attachment points and 3 mm. The total surface area of the structures is estimated at ≈ 8500 m^2, of which ≈ 4300 m^2 are located in the SGB.

As a first approximation we assume an equal temperature of 55 ^{o}C in all structures at nominal conditions in the SGB (1. bar; 55. ^{o}C).

The significant difference in the thickness (Tabl. 4.1) allows for transformation of the steel and air layers to an equivalent layer of reinforced concrete with a corresponding thickness: ≈ 0.08 m

$\delta_{c-s} = \delta_s.\lambda_c/\lambda_s = 0.0002$ m ; $\delta_{c-a} = \delta_a.\lambda_c/\lambda_a \approx 0.08$ m.

Finally, considering the large thickness and low heat transfer capability of the reinforced concrete layer, we have brought the task for definition of the short term heat transfer to the building structures to the basic problem for single side heating of an infinitely thick slab.

4.2 Initial and boundary conditions

a) Total inside surface of the structures in the SGB:	**F** ≈ 4300 m^2
b) Initial temperature of the structures:	$\mathbf{T_0}$ = 55 °C;
c) SGB temperature – as shown onFig.2**:**	$\mathbf{T_{SGB}} = T_{SGB}(t)$ **;**
d) Temperature on the inside surface of the structures:	$\mathbf{T_W} = T_{SGB}$

Problem: Evaluate the rate of heat transfer to the building structures: **Q(t)**, W.

4.3 Resolution

Computer codes like CONTAIN and MELCOR resolve the structure heating problem by splitting the slab into several layers and step by step definition of the temperatures and heat flux values on the layer boundaries (Fig. 3).

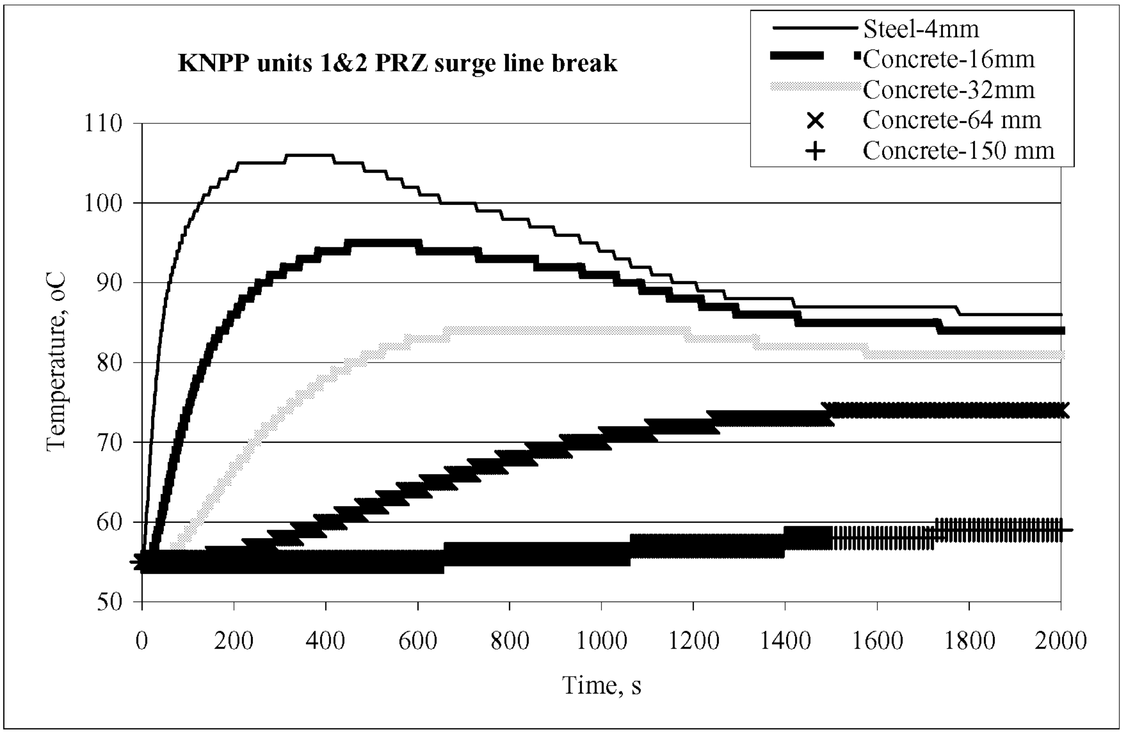

Fig. 3 CONTAIN results for the SGB wall heat –up (air gap assumed negligible)

For a general evaluation of the heat transfer rate it is more convenient to apply the analytic approach, presented in detail in [5]. It is based on the solution of the single dimension, non-stationary equation of heat transfer:

$$a_{sc}(\partial^2 T/\partial x^2) = \partial T/\partial t \qquad (4.3.1)$$

where: $\boldsymbol{a_{sc}} = \boldsymbol{\lambda_{sc}/(\rho_{sc}\, c_{p\text{-}sc})}$ = $1.36\text{x}10^{-6}$ m^2/s – temperature conductivity of reinf. concrete;
t , s – accident time;
x , m – layer thickness, counted from the inner SGB surface;
T = T(x, t) , °C – temperature at thickness **x** at time **t**.

The solution is generated by transformation of temperatures and thickness into dimensionless complex variables, followed by transformation of (4.3.1) into an ordinary differential equation of second order, which in turn is transformed into an ordinary differential equation of first order.
The average heat transfer rate for the interval from **0** s to ***t*** s accident time is defined, as follows:

$$\overline{Q} = (2/\sqrt{\pi})F(T_{SGB} - T_0)\sqrt{c_p.\lambda.\rho/t} \quad , W \qquad (4.3.2)$$

4.4 Results

Replacing of the given constants into (4.3.2) yields a simple formula for evaluation of the **average** heat transfer rate for the interval from **0** s to ***t*** s accident time

$$\overline{Q}_{SGB} = 10.4(\overline{T}_{SGB} - T_0)/\sqrt{t} \quad , MW \qquad (4.3.3)$$

Some results of the (4.3.3) application are presented in below: Tabl. 4.4

Period t, **min** / s	**0÷5** / 300	**0÷10** / 600	**0÷15** / 900	**0÷20** / 1200	**0÷30** / 1800	**0÷60** / 3600
$\overline{T}_{SGB}$, °C	**112**	**110**	**107**	**106**	**104**	**103**
$\overline{Q}_{SGB}$, MW	**34.1**	**23.1**	**17.9**	**15.2**	**12.1**	**8.3**

The analysis of the CONTAIN results for slabs heat-up confirmed the values of Tabl. 4.4.

An approximate differential profile of the heat transfer to SGB structures, derived by reverse interpolation of Table 4.4 is presented on Fig. 4 below:

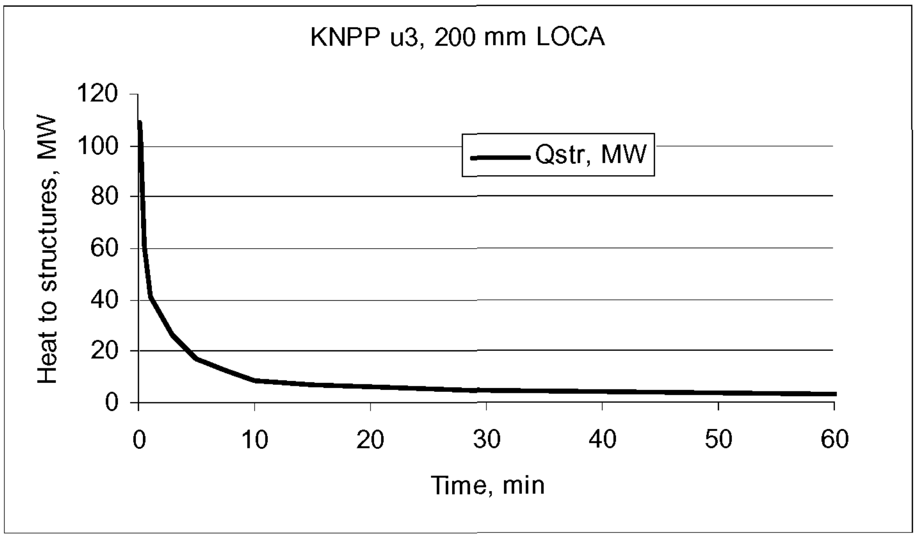

Fig. 4 Approximate profile of the heat transfer to SGB structures

Previous studies [1, 3] have shown that the total power of the spray system heat exchangers on NPP Kozloduy units 1, 2, 3 and 4 varies in the interval 12 ÷ 22 MW.

According to the results from our analyses for LOCA 200 mm, immediately after the final the closure of the 8 large flaps (from 5 to 20 min), the average release of energy from the broken primary pipe is ≈70 MW. Tab. 4.4 and Fig.4 allow for evaluation of the average heat transfer to the building structures during this period: ≈ 9 MW. Evidently, ≈ 12 % of the thermal energy, injected into the SGB is transferred to the building structures, which proves the strong influence of this process on the overall development of the accident.

Another aspect is the average rate of heat transfer per square meter: ≈ 2 kW. The phase transition energy in the range of temperatures 105÷112 oC is ≈2200 kJ/kg. This means, that the rate of condensation is ≈ 0.001 kg/m^2s or ≈4. kg/s for the whole surface of the SGB walls. This quantity is ≈15% of the condensation efficiency of one spray pump (≈28 kg/s at 200 kg/s SS flow rate).

5. Conclusions

The analytical method, presented in this paper, is an effective tool for evaluation of the heat transfer to the building structures.

The heat transfer to the building structures has a strong influence on the energy balance in the confinement during various accidents.

The rate of condensation on the SGB building structures is ≈15% of the condensation efficiency of one spray pump.

The results of the reviewed analyses explicitly show the high importance of the correct modeling of the building structures for the purposes of calculation of the confinement parameters.

References:

[1] ENERGOPROEKT-PLC , A complex analysis of 200 mm LOCA accidents for KNPP units I-IV. Rev. 1., Sofia, July 2000 (in Bulgarian language)

[2] ENERGOPROEKT-PLC , Analysis of 200 mm LOCA accidents for the modernization of the Accident Localization System of KNPP units 3 and 4. Rev. A, Sofia, Jan. 2001 (in Russian language)

[3] ENERGOPROEKT-PLC Analyses for analytical validation of EOIs for KNPP units 3 and 4. Rev. 0., Sofia, March 2001

[4] Set of design and operation data for units I-IV, provided by KNPP for the “LOCA 200” analyses, agreed with the Kurchatov Institute, Russia

[5] Dr. M. Lakov Technical University of Sofia, Department of Thermal and Nuclear Energy Set of lectures on heat transfer and heat exchange in the power generation industry.