# ELABORATION AND VERIFICATION OF A PTS MODEL



by

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**Abstract**
This work concerns to pressurises thermal shock (PTS) phenomena, it is rapid cooldown of the primary system by low temperature water injection from the emergency core cooling system (ECCS). To assess the effect of a PTS event calculations and experimental work are equally necessary. The purpose of the present was to prepare the PTS analysis of Angra II RPV located near to Rio de Janeiro. This paper presents the method and the results of the calculations used to design an optimal RPV model.
Keywords: PTS modelling, stress and temperature distribution, RPV

**Introduction.**
The primary reactor circuit is important key on the nuclear power plant safety. It is submitted to different thermal and mechanical loading during normal operation. During normal operation the cooling water temperature and the PWR wall temperature differs only a few degree Celsius. The design stress analysis calculates the safety factors during different operational modes , and fracture mechanics is used to evaluate the stability of the real and hypothetic flaws. In case of the operation of ECCS the difference between the vessel wall and the coolant temperature can be as high as 270°C. The stress, strain and temperature distribution -as well as the material toughness- change dynamically. The most extreme example of this process is the PTS event, which is the highest load an RPV must survive without losing its integrity even at the end of the lifetime, when the core zone toughness is degraded by thermal and irradiation effects. This dynamic stress and strain changes can be analysed only by using sophisticated codes. These codes must be verified by model experiments.
A test facility for PTS study is under development at CDTN (Nuclear Technology Developing Centre).
It will model the ANGRA II RPV. The main features of it:

Table 1 - Angra II PV

| Dimensions | Values on mm |
|---|---|
| Internal diameter | 5000 |
| Thickness | 250 |
| Length | 9748 |
| Material | 22NiCrMo37 |

The design steps of the vessel model is presented in this work.

**The test facility**

The test facility to be constructed will be similar than the facility used in Finland Experiment constructed at Prometey Institute/Russia[1,2]. The vessel model will be heated electrically e.g. by resistor shielding, the model will be placed inside a pool upon its one face. The heating system is removed and cooling water flow from storage tank will cool down the model from outside. The cooling water storage tanks will be in elevated position, the water will flow by its potential energy. During heating and cooling periods the model temperature and stress distribution will be measured by thermocouples and high temperature strain gauges.

**Design of the model vessel**

**Basic design requirements**

The model was designed to satisfy the following requirements:

- maximum available similarity with the RPV of ANGRA II Station (dimensions are given in table 1.
- use the world-wide collected experience on PTS modelling
- to produce easily measurable temperature and stress transients (High rate of stress changes needs expensive data acquisition systems)
- no plastic deformation should occur in the model during the tests. In case of plastic, or even non linear elastic deformation (out of the validity of the Hooke's law) the strain gauge measurements gives false results. Therefore the highest stresses should be limited to yield point
- keep the construction and operational costs low
- using steel available at the Brazilian foundry
- the size of the model should be beyond the machining capabilities of CDTN

**Calculation of the optimal model geometry.**

On the base of the above mentioned requirements a structural steel SAE 8620 was selected as model material. The properties of this steel are given in table 2.

The model maximum temperature were selected according to the operational temperature of Angra II, while the cooling water temperature follows the average weather of Belo Horizonte, where the facility will be located.:

- the model vessel max. (heated) temperature: $T_h = 300°C$
- cooling water injection temperature: $T_c = 30$ °C

Table 2 - Material properties

| | |
|---|---|
| Yield stress (MPa) | 400 |
| Thermal Conductivity Coefficient (W/m °C) K | 36 * |
| Young Modulus E (GPa) * | 200 |

* High temperature value

The requirements and other boundary conditions limited the model diameter max.: 500 mm and the length max.: 1000 mm. The only free dimension during the model design became the wall thickness.

To find the optimum value of the wall thickness 7 different calculation was performed. The minimum calculated wall thickness was 21 and the maximum was 126 mm[3].

**Calculation of thermal stresses..**

The ACIB-RPV *Analytical Calculation of Integrity of Beltline of Reactor Pressure Vessel* code was used to calculate the temperature and stress distribution at Atomic Energy Research Institute - AEKI - at Budapest/Hungary. This is an analytical code using similar equations then the US NRC code VISA[4]. .

The program inputs are: Young Modulus E, heating $T_h$ and cooling temperature $T_c$ , thermal conductivity coefficient K, heat transfer coefficient in the function of the temperature, pressure, wall thickness and cladding parameter. Since the model will not be pressurised, the pressure value was 0 during all calculations. The model vessel is not cladded therefore the cladding parameters are the same than base steel and thickness near zero value was used. (For mathematical reasons 0 value is not allowable in the code)

The dimensionless Biot-Savat number was calculated for Angra II vessel, and this value became used for the model calculations to ensure the conservatism during the model design..

Two heat transfer coefficients were used. When the model surface temperature is over 100 C boiling is supposed resulting a increased value.

Table 3- Heat transfer coefficients used

| Temperature (°C) | 0 to 100°C | 100 up to 300°C |
|---|---|---|
| Surface Heat Transfer Coefficient - h (W/ $m_L^2$. °C) | 5.000 | 30.000 |

The electrical furnace uniformly heat up the model, and the cooling water is cover rapidly the outer surface too. This aloud to use a simple one dimensional calculation, neglecting the temperature differences along the model height.

The temperature distributions during the model cooling were calculated periodically. From the results cooling diagrams was elaborated at the outer surface and at the location 12 mm distance from the inner surface . Three of these calculated cooling diagrams are shown on Fig. 1-3.

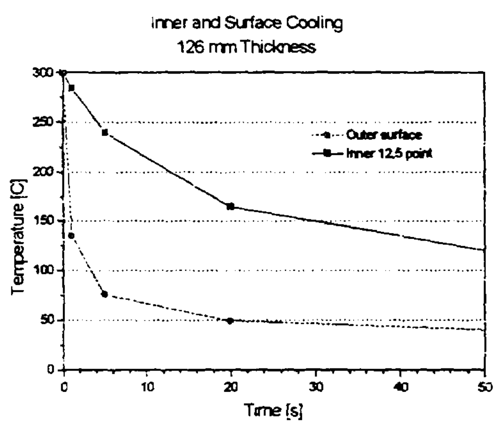


Figure 1 - Cooling diagram of the model with 126 mm wall thickness. Locations:
a.) Outer surface
b.) 12 mm from the inner surface

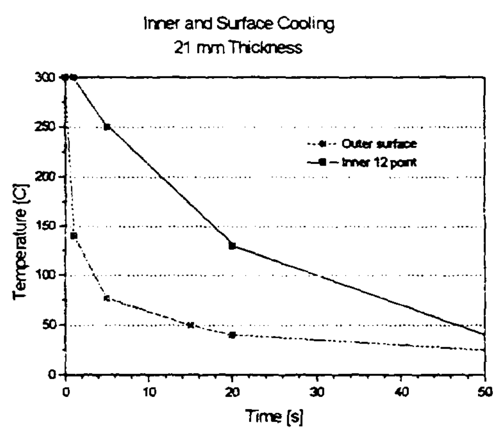


Figure 2 - Cooling diagram of the model with 21 mm wall thickness. Locations:
a.) Outer surface
b.) 12 mm from the inner surface )

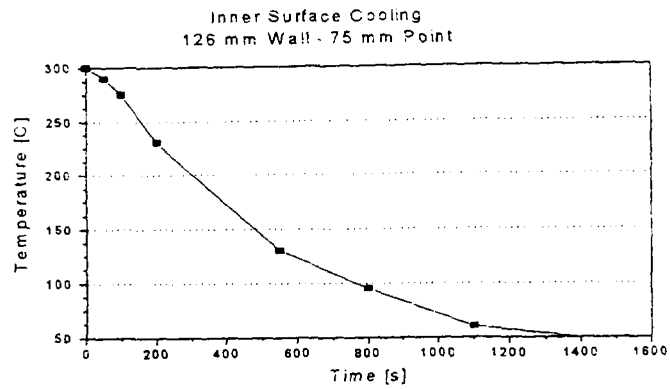


Figure 3 - Cooling diagram of the model with 75 mm wall thickness. Locations:

During the first 10-15 seconds the temperature distribution is independent from the model wall thickness in the range considered. After this initial period the different models shows different temperature gradient, and as consequence the stress distribution is also become different

Table 4-6 give some examples how the wall thickness affect the cooling rate of the outer surface.

Table 4- Model surface temperature after 50 seconds cooling

| At 50 seconds | | |
|---|---|---|
| Thickness (mm) | 21 | 126 |
| Temperature (°C) | 24 | 38 |

Table 5- Time to reach 40 C surface temperature

| to 40 °C temperature | | |
|---|---|---|
| Thickness (mm) | 21 | 126 |
| Time (sec.) | 25 | 40 |

Table 6- Necessary time interval to reach uniform temperature distribution along the wall thickness

| To uniform temperature along wall thickness | | |
|---|---|---|
| Thickness (mm) | 21 | 126 |
| Tempo (sec.) | 60 | 1700 |

The stress analysis has shown that the difference between the maximum values of the compression and tension stresses are increasing with the model thickness. Optimum wall thickness can be chosen according to the surface stress level required for good measurement.

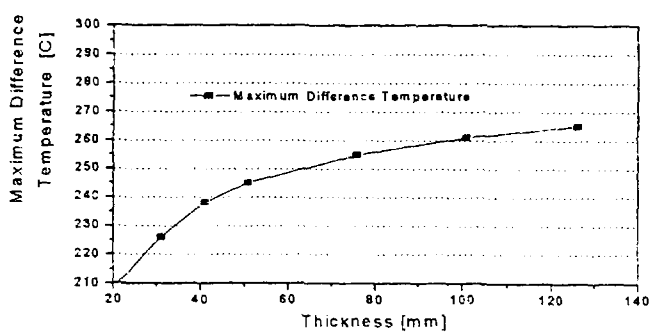


Figure 4 - Maximum difference between outer and inner surface temperature.

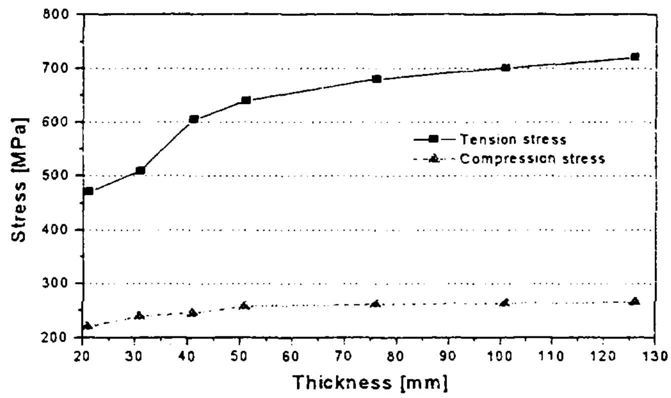


Figure 5 - Maximum stress values caluclated on differently thick modells The max tension stress occurs at the outer surface and maximum comperssion stress occurs at the inner surface.

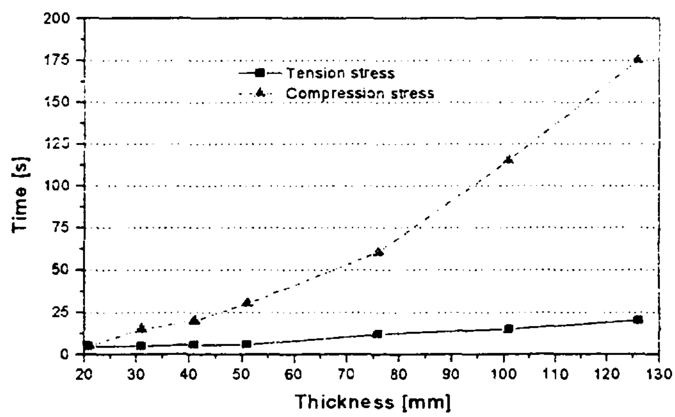


Figure 6 - Time to the peak stress values in case of different models

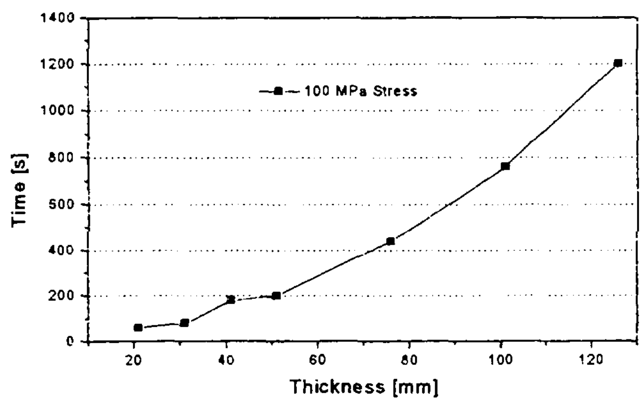


Figure 9 - Reaching time to 100 MPa stress in the fuction of the model wall thicknesseach thickness

Figs 6 and 7 shown, that the peak stress values are increasing rapidly with the thickness up to 50 mm. Increasing thickness over 50 mm has smaller effect, that is the unlimited increase of the model diameter has no practical advantage.

## Conclusion

a) The optimalised model dimensions will be: 1000 mm length, 500 mm external diameter, 330 mm inner diameter (85mm wall thickness) The surface stress transients easily can be measured by strain gauge at this thickness value.

b) SAE 8620 steel needs to be thermally treated to achieve high yield strenght value on the surface to avoid plastic deformation.
The suggested heat treatment: heating up to 850- 950 C, following water cooling to ambient temperature. The resulted yield point will be approximately 800 MPa which is appropriate to the tests]

c) Model can be used for crack initiation and arrest studies by repeating the test cycles
d) Finally thermal fatigue ageing can be evaluated by mechanical testing of the model material.

d) The model have been designed to test at 300°C initial vessel temperature and 30°C cooler temperature. The maximum stress in this case will be 680 MPa. The model can be operated without previous thermal treatment of the steel by decreasing the initial temperature or increasing water temperature.

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