The Methodology of Spent Fuel Containers Nuclear Safety Proving by Simulation

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Abstract. *A description of an actual status of documentation of nuclear safety for burned down fuel transport containers C-30 is given in this article. An alternative frame for this proving is given at the same time, too. The new alternative consists of mathematical modeling of container and after that in physical-thermal computation of container nuclear safety from measured data. The main phases of the methodology, as well as the model building, the verification of the obtained model, measured parameters estimation, measuring systems realization, first results and next steps are described in the article. The methodology can be used for all types of containers for burned-down fuel transport.*

The proposed methodology has resulted from Nuclear Regulatory of Slovak Republic requirements. The organization requires the duplicate proving of all reliability and safety parameters of systems used in nuclear power engineering. The suggested method is a topic of an APVV-0308-07 project, solved in co-operation of Faculty of Materials Science and Technology (represented by Institute of Applied Informatics, Automation and Mathematics) and Research Institute of Power Plants (VUJE), joint stock company Trnava. The methodology is new and it brings significant theoretical and practical benefits.

Keywords. Transport container, burned-down nuclear fuel, security, simulation

1 Introduction

The conditions for using of transport equipments (containers) for burned down nuclear fuel are defined in international and in Slovak legislative documents (the IAEA Safety Standards Series TS-R-1, the Slovak law about peaceful using of nuclear energy No. 541/2004, the Notice of Nuclear Regulatory of Slovak Republic No. 57/2006 about requirements for nuclear materials transport etc.).

The parameters which must be observed and documented are defined in those documents. The limits and safety parameters of containers are estimated by analyze and by computations. The used computations, methods and processes are derived from power (nuclear and physical) conditions and they are accredited by authorized institutions.

The JAVYS, joint stock company, is the user of the transport containers. The effort of this company is to verify the main container's parameters from security point of view with a help of measurements or alternative computations.

This article describes the methodology, which can precise and verify the nuclear and physical computations for the estimation of residual power of burned down nuclear power transported in containers. The methodology bases on the design of mathematical model of the container as a thermic system.

It will be possible with the help of the model to estimate by physical-thermic computations the residual container's power from thermic values after the measurement of relevant parameters. The results can be used for the verification of actually used nuclear and physically based methodology.

2 The present-day state

2.1 Engineering solution of the container

The covering equipments (containers) C-30 are used for the transport of the burned-down nuclear fuel of the type VVER-440. The containers are dedicated for the transport and the manipulation with boxes of burned-down cassettes. The JAVYS disposes with 4 containers C-30 nowadays. The using conditions are defined for this owner and operator.

The body of the container is massive, with external axial ribbing, in the configuration of closed cylindrical box. (Detailed description in [2]).

Table 1:
Engineering parameters of the container C-30

Weight of the empty container	67 300 kg
Weight of the cover	5 500 kg
Weight of the full container (with water):	
- with the box KZ 48	84 600 kg
- with the box T-12	80 260 kg
- with the box T-13 (18 cassettes)	79 150 kg
Total height without the cover	4 267 mm
Total height with the cover	4 367 mm
External diameter	2 500 mm
Internal diameter	1 475 mm
Internal volume	6 000 l
Maximal operating pressure	0,7 MPa
Experimental pressure	1,05 MPa
Operating temperature	-40 – 100 °C
Transport position	vertical

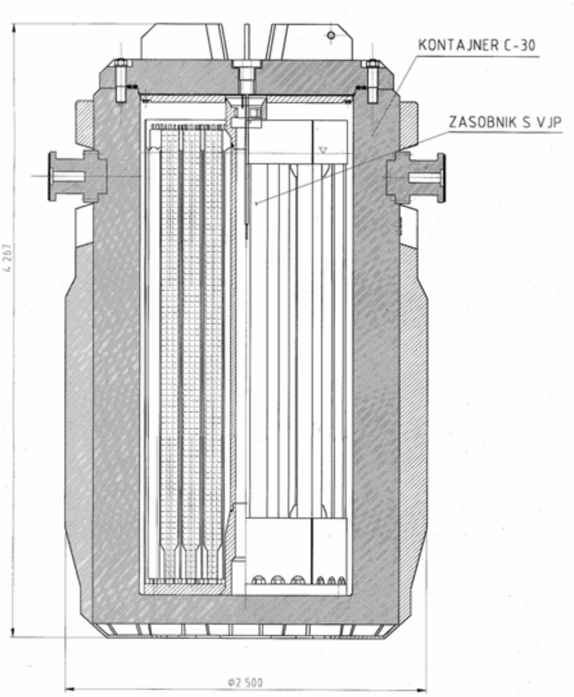

Figure 1: Container C-30

The container C-30 is used for the transport of fuel cassettes of reactor VVER-440, which are situated in a compact box KZ-48 or in boxes T-12 or T-13.

The compact box KZ-48 can contain maximally 48 fuel cassettes. The cassettes consist of sticks of UO_2-tablets. The sticks are coated by zircon alloy. They are ordered to trigonal grid in the box. The mass of uranium in the cassette cannot exceed 122,7 kg, what is the safe value used in the container's security documentation process.

On the ground of keeping of temperature limits the total residual power of transported fuel cannot exceed 24 kW and the power of each cassette must be under 605 W. The standards of dose radiation power fulfillment need, that the total neutron intensity should be lower than $7{,}95x10^9$ neutron/s. and the intensity of gamma-radiation should be under $1{,}65.10^{17}$ photons/s. The radioactivity of container is under permitted limits, if the total activity of transported fuel do not overreach $2{,}35.10^{17}$ Bq.

The box T-12 can contain maximally 30 fuel cassettes of VVER-440-reactor. The cassettes and their parameters, as well as the total power and activity of fuel, are the same like in case of KZ-48.

The box T-13 can contain maximally 18 hermetically closed packages, each of them with one VVER-440-cassette. Because the construction of the box is the same like in the previous case and the number of cassettes is lower, the values of T-12 are valid for T-13, too.

2.2 Calculation of physical parameters

The design values of physical parameters of container C-30 with the compact box KZ-48 or with the box T-12 can be reached some time after finishing of active role of fuel in a reactor. The burned-down cassettes are moved from active reactor zone into store pools, where a cooling process proceeds. The residual power, intensity radiation and fissionable products activity decrease.

The pool capacity is restricted; therefore the maximal cooling time is limited. It depends on fuel production in various reactor campaigns. This number goes down with rising fuel enriching and the maximal cooling time increases. The analysis shows, that maximal storing (cooling) periods for various enriching values of fuel are: 3,6 % - 4 years, 4,0 % - 4,5 years, 4,4 % - 5 years.

2.2.1 Source data

The computations of physical parameters of container are based on the assumption that the middle burn-up of cassettes 50 MWd/kgU is reached by staying of fuel in the reactor during 5 campaigns with the period of 290 effective days and with the maximal burn-up of the cassettes 55 MWd/kgU. The initial value of the fuel enriching is 4,4 %.It is supposed that the container is full (48 cassettes in the case of compact box KZ-48, 30 cassettes in the case of T-12) and that the cassettes are identical with the middle burn-up 50 MWd/kgU. All computations were done for the cooling periods 2,5 – 5 years.

2.2.3 Computing methodology and results

The American computing complex SCALE 4.3 (modules SAS2 and ORIGEN-S) is used for the computation of physical parameters. This modular system is dedicated to properties analyzing of fresh as well as burned-down fuel sets.

The computations of residual power, intensity and activity are performed by the module ORIGEN-S. The computations are based on the system of linear differential equations of the 1st. order. The equations describe the creation and the destruction of nuclides in the fuel.

The results of computations are the residual power [kW], the activity [Bq], the intensity of photons sources [f/s] and the intensity of neutrons sources [n/s] according to the cooling time. The computing process is described in details in [2].

3 Proposed methodology

The Nuclear Regulatory of Slovak Republic requires a verification of present methodology. Therefore a new research project solved in co-operation of more institutions was submitted. The goal of the project is a design of a new methodology for the estimation of residual power of burned-down fuel in containers.

3.1 Main steps

The main steps of the proposed methodology are:

1. **Mathematical model design**. The container is modeled as thermical system, so that the residual power can be determined from known and measured values. The model should be universal for various container types and for various conditions.
2. **Specification of the way of the measurement and of the computation of needed input values** (thermical coefficients, temperatures, …). These values are given by the mathematical model. Some parameters of container can be obtained from technical description of container; the other must be measured or calculated.
3. **Measuring systems building**. New systems and tools, as well as container’s adjustments and modifications according to step 2 should be proposed and realized.
4. **Measuring**. Experiments and measuring according to step 2 by systems according to step 3 will bring the database of values.
5. **Experiments evaluation and verification**. The obtained results must be corresponding with the values from traditional (nuclear and physical) computations.
6. **Methodology generalization**. The methodology must be valid and usable for all container types.

The main point of the methodology is the step 1.

The detailed description of this step is given in [1], where the relationship (1) is derived and proved:

$$P = S.a\left(-T_e - \frac{T_i \sum_{i=1}^{N} e^{-\frac{t_i Sa}{K}} - \sum_{i=1}^{N} Y_i - T_i e^{-\frac{t_i Sa}{K}} + \sum_{i=1}^{N} e^{-\frac{t_i Sa}{K}} Y_i}{\sum_{i=1}^{N} e^{-2\frac{t_i Sa}{K}} + N - 2\sum_{i=1}^{N} e^{-\frac{t_i Sa}{K}}} \right)$$

Where:

- P: input power,
- S: surface area of the container,
- a: middle value of thermal convection,
- T_e: temperature of environment,
- T_i: initial temperature of the container,
- Y_i: temperature of container’s surface
- t_i: time
- K: thermal capacity of the container
- N: the number of measured values

The surface S of the container and the coefficient a can be determined from the known input power P (given by electrical heating) and from temperatures difference T_f-T_e (after and before the heating process):

$$a.S = \frac{P}{T_f - T_e} \qquad (2)$$

It is clear, that the main problem of the proposed methodology is the temperatures measurement. The way of measurement, measuring system and results processing are described in [3] and [4].

3.2 Measurement system

About one hundred temperature sensors PT100 (for purpose of the fuel residual power measurement) were systematically placed on the outer casing of the container C30 according to the beforehand prepared allocation pattern. For the data acquisition in the measurement system are used the Advantech ADAM 4015 modules, which are able to communicate with the master system using the ModBus/ASCII protocol over the EIA-485 industrial bus. Every ADAM 4015 provides the connection with six resistive temperature sensors, which are interconnected by the three–wire connection to compensate the disturbances caused by the cable lengths. The lengths of the cables are minimized thanks to the strategic placement of the ADAM 4015 modules in the space around the container. These steps should eliminate the influence of unwanted noises superposed on the measured value.

One of the acquired parameters is the reference temperature inside of the container measured by the precise thermometer CHUB E4 - because of this we are able to satisfy the requirements for stabilization. The CHUB E4 is connected to the PC through the COM port.

Seeing that the directly measurement of the delivered electrical power is not possible, we are measuring the delivered voltage and compute the power.

Voltage measuring devices are three industrial voltmeters Orbit Merret OM352AC (one for each phase) with the ModBus/ASCII communication protocol, which gives us the opportunity to connect them to the same network as the ADAM 4015 modules.

Three thyristor units CD3000M are used for the electrical power control and also as the heating element – to each thyristor unit are linked four resistive heat elements with power about 2kW. Theese units are communicating through the EIA-485 industrial bus with the ModBus/RTU protocol. The Thyristor units CD3000M are able to switch the currents in wide range from 15A to 110A, because of this we have a wide spectrum of the electrical power control [4].

4 Next steps and expected results

Experimental measurements are being executed at this time. After the successful evaluation of the experiment results will be the methodology finalized and implemented into the practise to provide the duplicate proving of the reliability and safety parameters by the BFF transporting. The measured values will be used as input data for the calculation in application software system. The system realizes the computation, displays it in a table and in a graphical form and compares the results with results of nuclear computations.

The presented solution is new and original in Slovak republic and in international level too. It will be registered and protected as industrial design.

The social benefit of the methodology is the verification of data published in safety documentation, given by mathematical-analytical methods. This verification increases the confidence to process of spent fuel container exploitation.

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