THE NEW METHODOLOGY VERIFICATION FOR THE RESIDUAL POWER DETERMINATION OF SPENT NUCLEAR FUEL

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Abstract

The new methodology for the determination of residual power of spent nuclear fuel by temperature measuring of containers was developed. The container without fuel was heated by electrical resistant spirals with known electrical power, which simulates the residual power of the transported nuclear fuel. The measured temperatures of the container surface and the environment were used for the design of the thermic mathematical model. This model can be backwards used for the determination of the power of transported fuel in real container's operation. This article describes briefly the new methodology and its verification.

Key words

verification, methodology, residual power, C-30, modeling

Introduction

The today's determination of residual power of nuclear fuel is based on computational program. The computing complex SCALE 4.3 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.

ORIGEN-S computes time-dependent concentrations and radiation source terms of a large number of isotopes, which are simultaneously generated or depleted through neutronic transmutation, fission, and radioactive decay. Provisions are also provided to simulate input feed rates, and physical or chemical removal rates from a system. The calculations may pertain to fuel irradiation within a nuclear reactor, or the storage, management, transportation, or subsequent chemical processing of spent fuel elements.

ORIGEN-S is widely used in nuclear reactor and processing plant design studies, design studies for spent fuel transportation and storage, burnup credit evaluations, decay heat and radiation safety analyses, and environmental assessments. The matrix exponential expansion model of the ORIGEN (Oak Ridge Isotope GENeration) code is unaltered in 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 Nuclear Regulatory of Slovak Republic requires the verification of present methodology alternatively.

Therefore new research projects solved in co-operation of more institutions (incl. foreign) have been submitted. The new methodology and achieved results in determination of residual power of spent nuclear fuel by temperature measuring of the container have been proposed as result of research project and have to be verified now.

The burned-out fuel in a container radiates energy, it is a fact. The radiated energy is equal to the energy submitted into environment. The computations described in [1], [2], [4] demonstrate, that the temperature of container's coat can be given by the equation:

$$T(t) = T_e + \frac{P}{\alpha S} + \frac{-T_e - \frac{P}{\alpha S} + T_0}{e^{\frac{\alpha S t}{K}}} \quad , \tag{1}$$

where
T = temperature of the container's coat,
P = heating power (electrical or nuclear),
T_e = temperature of the environment,
S = surface area of measured place,
α = heat transmission coefficient,
K = thermal capacity of the container,
T_0 = initial temperature of the of the coat,
t = time.

Modifications with the goal to eliminate S and α given in [2], [4] change the expression (1) into the equation (2):

$$T(t) = T_f + (T_f - T_0) e^{-t \frac{P}{K(T_f - T_e)}} \quad , \tag{2}$$

where:
T_f = final temperature of the coat (after temperature stabilization).

The expression (2) means, that the temperature of the coat changes according to Figure 1 after a step change of heating power.

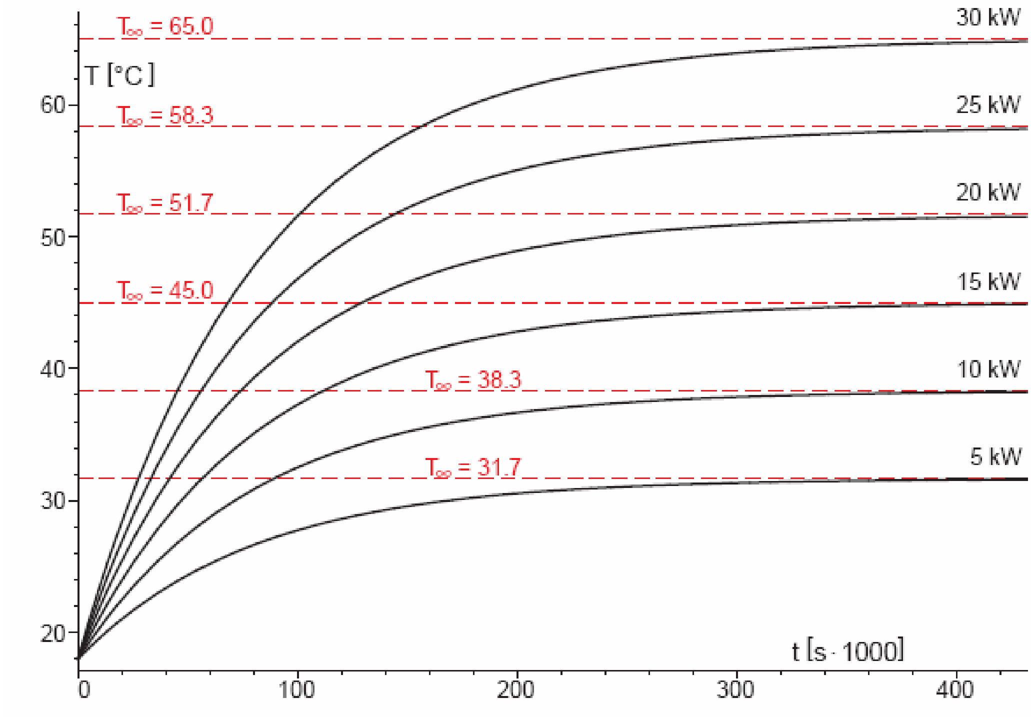

Fig. 1 *Temperatures by different heating power*

As reference values were used T_0 = 18°C, T_e = 25 °C, the thermal capacity K = 59 930 $kJkg^{-1}K^{-1}$ was computed for 75 000 kg of steel and 5000 kg of water.

New methodology

The authors have proposed a new methodology for residual power estimation. The base for the methodology is the equation (2) and is described in [1], [2], [3], [4]. The idea of a new approach is: If the relation between the heating power in container and the temperature of the container's coat is known, so the heating power can be estimate according the measured temperature. Therefore the dependence of the temperature and the heating power has to be estimated. That means practically:

1. The container without fuel (but in the same external conditions like in real operation) will be heated step by step by electrical spirals with the rising power of 4, 8, 12, 16, 20 and 24 kW. The temperature of the coat will be measured.
2. Each measurement should be finished, when the temperature of the coat stabilizes.
3. The container should be cooled down into environmental temperature after each measurement.
4. The time and height dependences of external temperature should be approximated by polynomial function of the 6th grade in the time and of the 3rd grade in the height. The coefficients of the polynomare computed according to least square method.

The measurement concept is described in [3, 6]. Three tetrads of resistant spirals with the total power of 24 kW controlled by thyristors were used for the heating. The temperature was measured by 102 sensors. 84 of them were situated on the surface, 3 of them in the container and the rest was used for the measuring of the surrounding temperature.

The thermo sensors were situated uniformly on the cylindrical container's coat in 7 height levels. 12 sensors were used in every level. The Fig. 2 gives the values for P = 18 kW as an example of measured temperature courses.

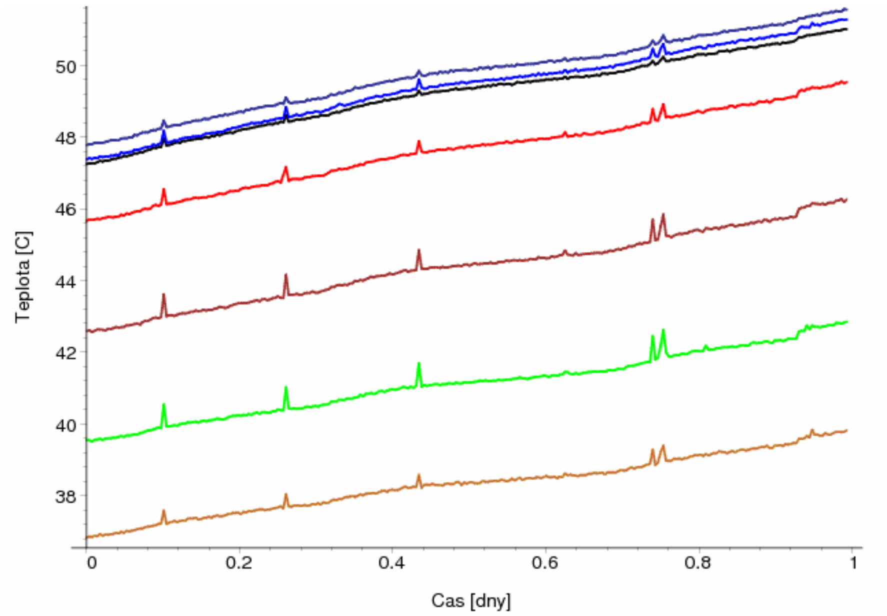

Fig. 2 *Temperature of container in 7 height levels for P = 18 kW*

The next deductions can be done from the initial measurements:

- The temperature balance with the environment was not obtained within 24 hours from the start of measurements.
- The external temperature is affected by heating power during measuring process.
- There is a height gradient of the environmental temperature in the measuring room during measurements.
- The environmental temperature oscillates gently during 24 hours.

If the environmental temperature changes smoothly during a day and a night, the changes affect the container's coat temperature only a little, because the big heat capacity of full container (its weight is more then 84 000 kg) do not allow the rapid reaction to external conditions changes. The measured values of coat's temperature is given in figure 3.

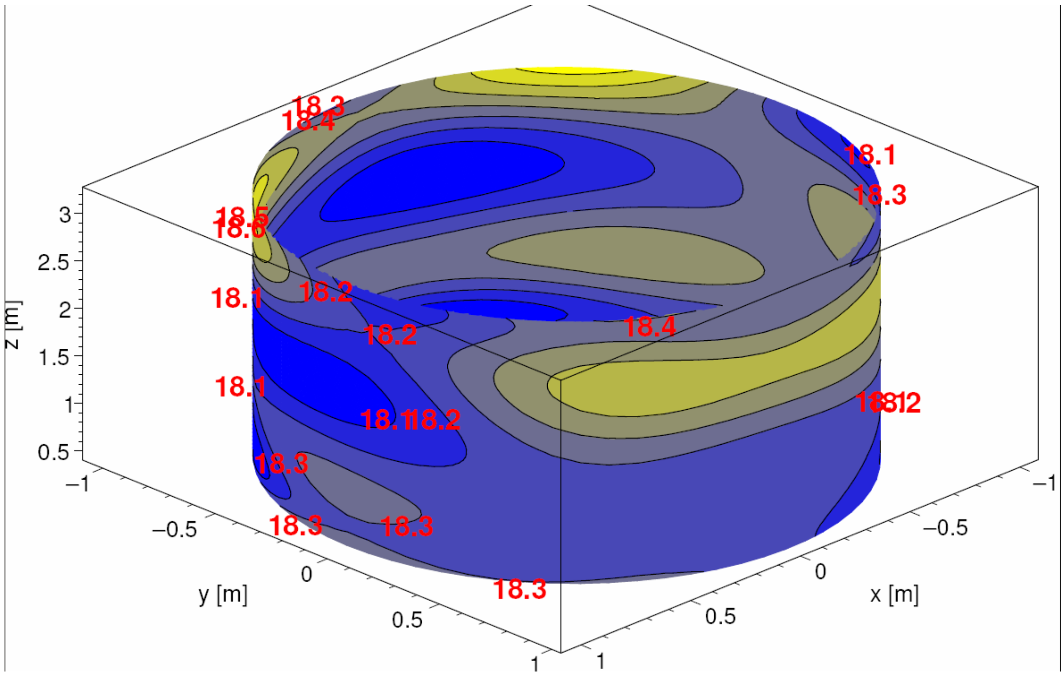

Fig. 3 *Temperature of container's coat for P=18,45 kW*

Proposal of verification

The methodology was verified by measurements of coat's temperature by an unknown total power of heating spirals.

The measured temperatures have been used for the heating power estimation. The power has been estimated for each sensor individually. The statistical methods of data processing have been used for total number of 84 sensors. The mean value, mean square deviation and relative, as well as other statistical values has been computed.

The measured temperatures in height levels, as well as computed temperatures are presented as a result of verification in figure 4 and 5.

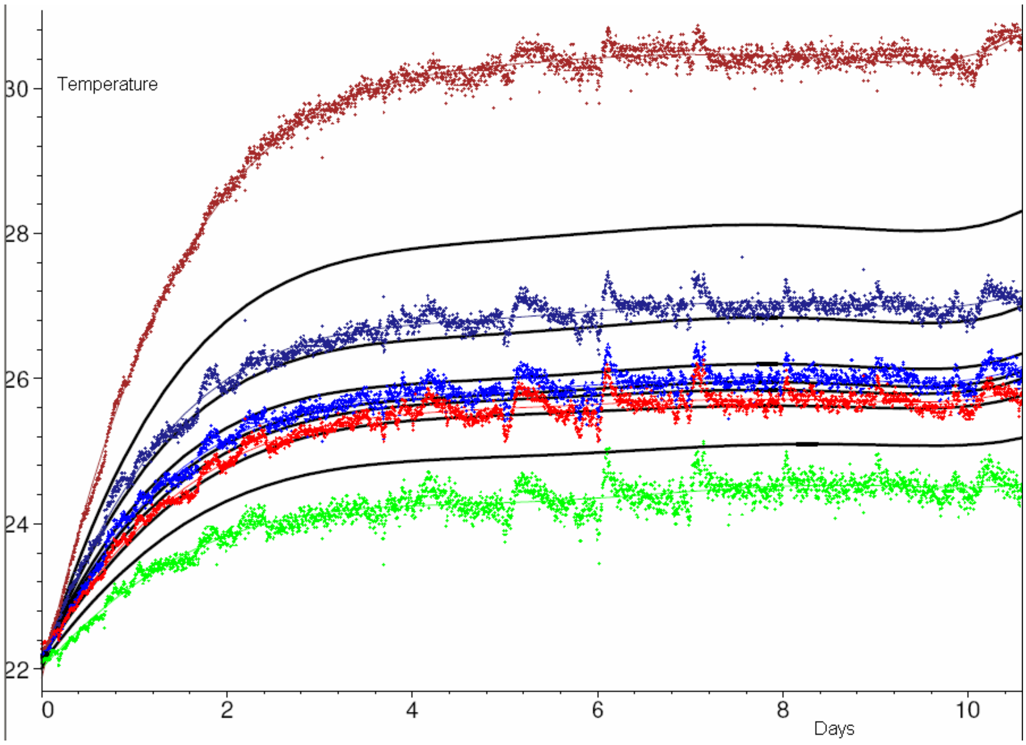

***Fig. 4** Measured and computed (black lines) temperatures in height levels*

The summarized results are:

Total heating power of spirals (this value was unknown for verification team): 18, 45 kW.

Estimated power according our proposed methodology was: 18.29 kW.

Mean square deviation: ± 0.16 kW.

Relative error: 0.89%.

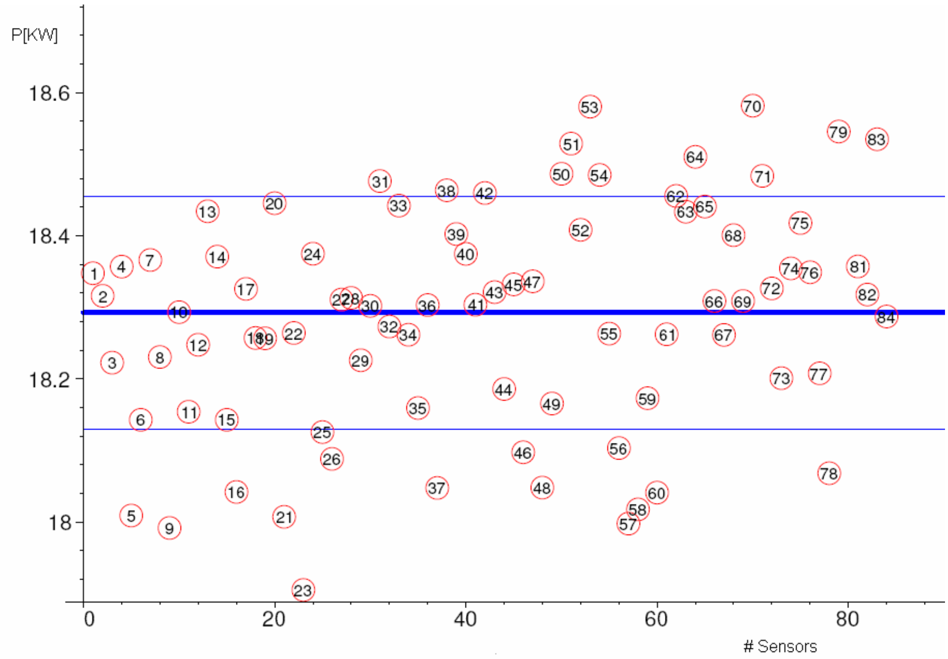

Fig. 5 The dissipation of power in dependence of particular sensors

Conclusion

The verification of the method confirmed our proposed approach. The achieved results are accurate enough. The methodology for residual power estimation can be used as complementary approach, which completes the used method based on the description of the creation and the destruction of nuclides in the fuel.

The presented solution is new and original in Slovak republic and in international level too. It increases the confidence to process of spent fuel containers exploitation.

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