Nuclear Energy in Central Europe '98
Terme Čatež, September 7 to 10, 1998

Concrete spent fuel storage casks dose rates

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Abstract

Our intention was to model a series of concrete storage casks based on TranStor system storage cask VSC-24, and calculate the dose rates at the surface of the casks as a function of extended burnup and a prolonged cooling time. All of the modeled casks have been filled with the original multi-assembly sealed basket. The thickness of the concrete shield has been varied. A series of dose rate calculations for different burnup and cooling time values have been performed. The results of the calculations show rather conservative original design of the VSC-24 system, considering only the dose rate values, and appropriate design considering heat rejection.

1. Introduction

Although existing storage locations for spent fuel are mainly spent fuel pools in nuclear power plants, dry disposal option dominates the plans and projects for the future. Main reasons are larger flexibility, low cost, and possibility of passive cooling and low level of supervision needed. Among different existing intermediate dry spent fuel storage systems, storage in concrete casks provides a safe and economical method for the dry storage of irradiated fuel at an independent spent fuel storage location. The TranStor Ventilated Storage Cask (VSC) System [1] is a good representative of such a system.

The system includes ventilated concrete cask, multi-assembly sealed basket and a transfer cask. The concrete cask provides structural support, shielding and natural convection cooling for a loaded multi-assembly sealed basket.

TranStor system storage cask VSC-24 is a vertical concrete ventilated storage cask designed for 24 PWR spent fuel assemblies with a maximum burnup of 35 GWd/tU and a minimum cooling time of 5 years. Considering the fact that recently achieved burnup of fuel assemblies is considerably higher (up to 50 GWd/tU) than the TranStor VSC-24 maximum allowed burnup, resulting in higher thermal and dose rate values, the use of the cask for the assemblies with extended burnup, without further investigation is not recommendable.

A series of concrete storage casks based on TranStor system storage cask VSC-24 has been modeled, and the dose rates at the surface of the casks as a function of extended burnup and a prolonged cooling time have been calculated. All of the modeled casks have been filled with the original multi-assembly sealed basket and the thickness of the concrete shield has been varied.

SCALE 4.2 code package [2] has been used for all calculations. The ORIGEN module [3] has been used for isotope depletion, heat production and neutron and gamma energy spectrum calculations. The SAS4 control module (Monte Carlo method) has performed simulations of gamma and neutron transport as well as dose rate calculations.

2. VSC-24 main parameters and calculational model

The original TranStor system storage cask [1] is a vertical concrete storage cask, composed out of a multi-purpose sealed basket (MSB) and a ventilated concrete storage cask (Figure 1.).

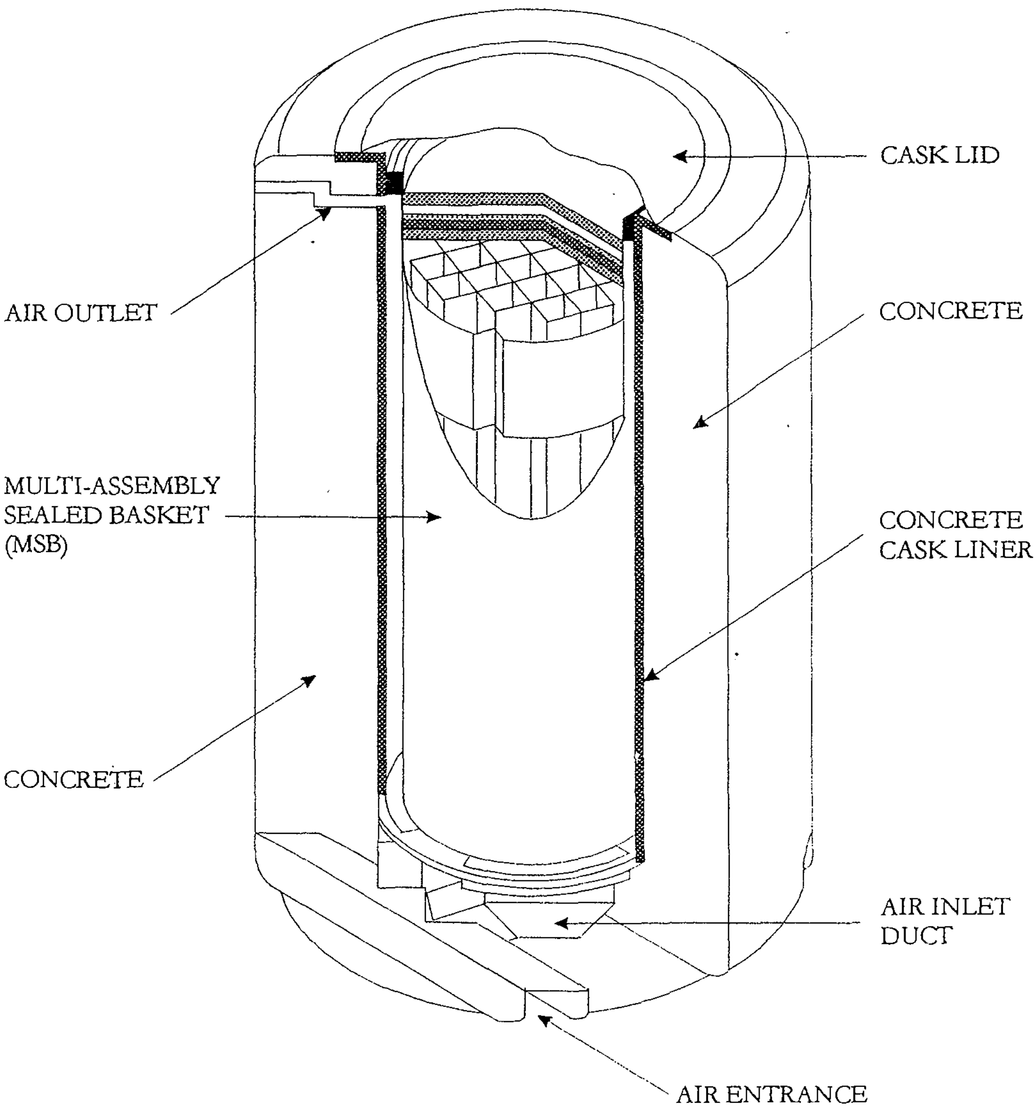

Figure 1. TranStor Ventilated Storage Cask-24 System

The MSB is capable of handling PWR as well as BWR spent fuel assemblies, and the capacity is 24 and 61 assemblies, respectively. The loaded MSB weights 39 (PWR) or 42 (BWR) tons and the operating temperature is 380 °C. The basic shape of the MSB is cylindrical with the following main dimensions: overall length is variable from 3200 mm to 4880 mm (the length taken for our calculation is 4000 mm); diameter 1676.4 mm; wall thickness 19 mm; lid thickness 165 mm; bottom thickness 19 mm. Whole MSB is made out of stainless steel. Cavity is filled with He at the pressure of 152 kPa (1.52 bar).

Ventilated concrete storage cask can be filled with one MSB. The weight of the empty casks is 112 tons, while the loaded one, weights 151 tons. Design heat rejection is 24 kW, while the peak cladding temperature is 378 °C (PWR) or 436 °C (BWR). Maximum designed burnup is 35 GWd/tU with the minimum cooling time of 5 years. The basic shape of the cask is cylindrical with the following main dimensions: overall length is variable from 5000 mm to 6100 mm (the length taken for our calculation is 5000 mm); overall diameter 3300 mm; cavity length is variable from 4445 mm to 4930 mm (the length taken for our calculation is 4500 mm); cavity diameter 1790 mm; wall thickness 781 mm; overall lid thickness 343 mm; bottom thickness 610 mm. The cask body is made out of reinforced concrete. Since the actual composition of the concrete wasn't available, we supposed the mixture of regular concrete and carbon steel with volume fractions of 16.15 % and 83.85 % respectively. Such an assumption has been based on the measured surface dose rate for the side of the cask which was 0.4 mSv/h for total burnup of 35 GWd/tU and 5 years cooling time [4]. A series of calculations, varying steel volume fraction in reinforced concrete had been done, until obtained surface dose rate matched the measured one. To reduce CPU time we simplified rather complex system geometry. The simplified geometry of the VSC-24 system is depicted in Fig. 2.

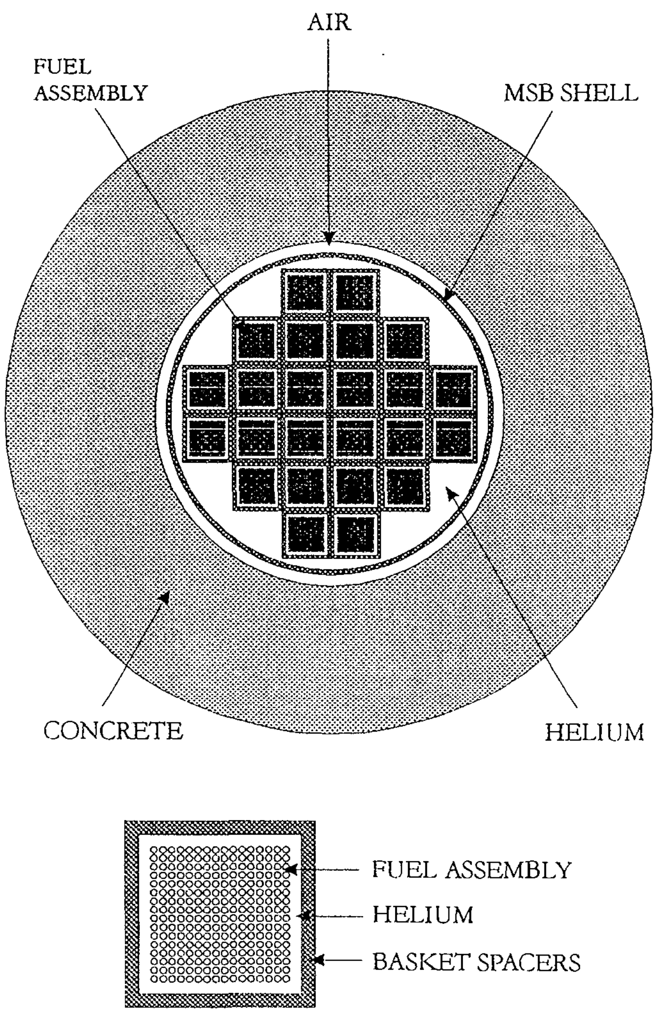

Figure 2 VSC-24 system horizontal cross section

Since the manufacturer's burnup limit for the VSC-24 system is 35 GWd/tU and recently achieved burnup at NPP Krško is 40-45 GWd/tU [5], we decided to perform the dose rate calculations in the 35-50 GWd/tU range. Under the normal nuclear power plant operational conditions a particular total burnup can be achieved with slightly different initial fuel enrichment, and therefore we varied that parameter as well. In order to get as much information as possible, concerning the dose rates, we varied the cooling time and the wall thickness. Neutron and gamma spectra obtained by ORIGEN module, were incorporated into the SAS4 sequence as a source spectrum. SAS4 calculations have been done with the IGO-3 geometry option, which explicitly represents fuel pins, and the only homogenization is done inside the pins.

Neutron and gamma dose rates were calculated using standard SAS4 surface detectors which give the average dose rate values through four imaginary hollow cylinders placed around the cask. Only the results of the detector on the cask surface have been taken into account. The SAS4 offers positioning of point detectors in any point outside the cask. That gives the possibility of flux and dose rate calculations as a function of detector position. We have performed point detector calculations as well. The results showed expected dependence of detector azimuthal position. Surface detectors were used, rather than the point detectors, mainly because of significantly smaller fractional standard deviation.

3. Results of the calculations

Results of the SAS4 calculations for gamma (total) dose rates at cask surface for the original VSC-24 system (the thickness of the shield is 78.1 cm) and for a series of casks with a reduced shield thickness, as well as ORIGEN calculation of total thermal power for every case, are given in Table 1.

The design dose rate limit of 0.2 mSv/h isn't reached in any of the cases for the original VSC-24 system. In the worst case (50 GWd/tU burnup and 5 years cooling time) the dose rate is roughly one third of the design value. On the other hand, the design heat rejection has been surpassed for 41, 44, 47 and 50 GWd/tU burnup and 5 years cooling time (shadowed fields in Table 1.). More then 5 year cooling time period is necessary for 41, 44 and 47 GWd/tU burnup, and more than 7 years for 50 GWd/tU burnup. The conservative design of the original system, considering only dose rates, suggested a series of systems with a reduced shield thickness to be modeled. The results of the calculations for all cases are given in Table 1. and depicted in Figures 3-6. The dose rate values obtained for the modified systems with a reduced shield thickness are also below the original design values. The only exception is the shield of 68.1 cm (10 cm reduced original thickness). In that case more than a five year cooling period is necessary (shadowed fields in Table 1.).

Table 1. Surface dose rates and heat rejection for the original and modified VSC-24 systems, as a function of starting enrichment, burnup and cooling time

Enr. (%)	Burnup (MWd/tU)	Cooling Time (y)	Heat (kW)	Surface Dose Rate (mSv/h) D_1=78.1 cm	D_2=73.1 cm	D_3=70.6 cm	D_4=68.1 cm
3.4	38000	5	22.4	4.38E-02	9.55E-02	1.45E-01	2.29E-01
3.4	38000	7	17.2	2.65E-02	5.94E-02	9.14E-02	1.39E-01
3.4	38000	9	14.9	1.87E-02	4.18E-02	6.53E-02	9.79E-02
3.4	38000	11	13.6	1.41E-02	3.25E-02	4.94E-02	7.38E-02
3.8	41000	5	24.1	4.66E-02	1.05E-01	1.61E-01	2.27E-01
3.8	41000	7	18.6	2.67E-02	6.49E-02	9.76E-02	1.46E-01
3.8	41000	9	16.2	1.91E-02	5.27E-02	8.42E-02	1.24E-01
3.8	41000	11	14.8	1.45E-02	3.34E-02	5.22E-02	7.97E-02
3.8	44000	5	26.3	5.02E-02	1.14E-01	1.62E-01	2.56E-01
3.8	44000	7	20.4	2.96E-02	6.86E-02	1.03E-01	1.59E-01
3.8	44000	9	17.7	2.05E-02	4.83E-02	7.25E-02	1.09E-01
3.8	44000	11	16.2	1.57E-02	3.62E-02	5.69E-02	8.50E-02
4.3	47000	5	27.9	5.08E-02	1.15E-01	1.78E-01	2.62E-01
4.3	47000	7	21.7	3.07E-02	6.83E-02	1.04E-01	1.65E-01
4.3	47000	9	19.0	2.18E-02	4.90E-02	7.48E-02	1.18E-01
4.3	47000	11	17.4	1.63E-02	3.77E-02	5.83E-02	8.72E-02
4.3	50000	5	30.2	5.59E-02	1.23E-01	1.88E-01	2.64E-01
4.3	50000	7	23.6	3.29E-02	7.41E-02	1.16E-01	1.78E-01
4.3	50000	9	20.6	2.30E-02	5.31E-02	7.94E-02	1.21E-01
4.3	-50000	11	18.9	1.77E-02	4.25E-02	5.97E-02	9.56E-02

Fractional standard deviation (FSD) for the neutron calculations was 3-4%, and for gamma calculations 1.9 - 2.7%. Since gamma dose rate is much larger than neutron dose rate (10-100 times), total FSD is roughly equal to gamma FSD. For the same reason, total dose rates are similar to gamma dose rates. The uncertainties of the results are much larger than the total FSD. Main causes for this are:

- Activities of irradiated (spent) fuel and neutron and gamma spectrum have been calculated using the assumption of spatially and timely constant neutron flux in reactor during the whole irradiation period.
- The axial homogeneous distribution of activity in fuel rods.
- Surface detectors give the average dose rate as a result of integration of neutron and gamma flux over a large cylinder surface. Because of the axially unsymmetrical position of the fuel assemblies in the cask there are regions outside the cask with different dose rate values [6].

4. Conclusion

The results of the calculations given in Table 1., and depicted in Figure 3., show that the design of the original TranStor VSC-24 system is rather conservative, when considering only the dose rate values. Manufacturer's design limit of 0.2 mSv/h isn't exceeded in any of the cases of the original design. The dose rate values obtained for the modified systems with a reduced shield thickness are also below the original design values. The only exception is the shield of 68.1 cm (10 cm reduced original thickness). In that case more than a five year cooling period is necessary (shadowed fields in Table 1.).

The design heat rejection has been surpassed for 41, 44, 47 and 50 GWd/tU burnup and 5 years cooling time. More than 5 year cooling time period is necessary for 41, 44 and 47 GWd/tU burnup, and more than 7 years for 50 GWd/tU burnup.

References:

[1] *Shipping and Storage Cask Data for Commercial Spent Nuclear Fuel*, JAI Corporation, Fairfax, Virginia, 1996

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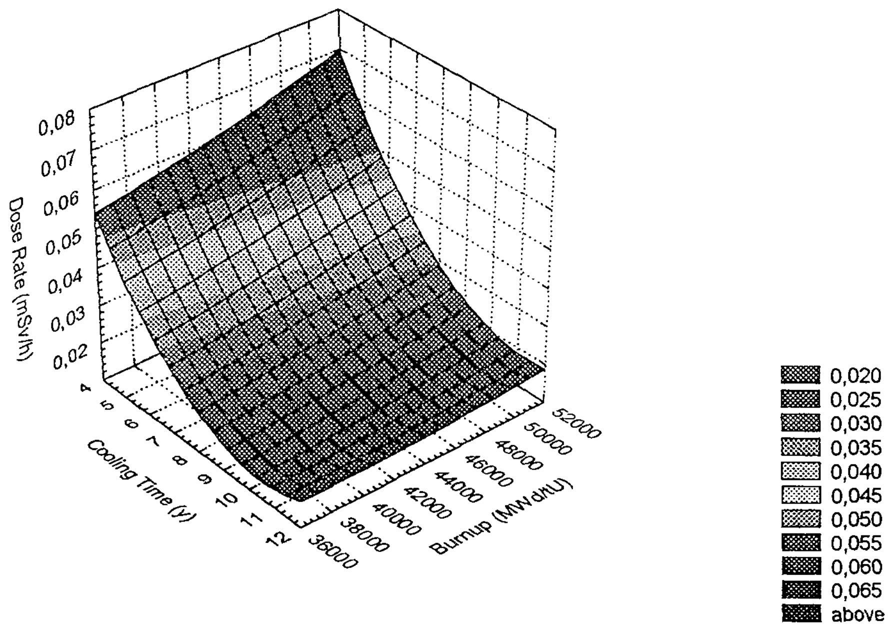

Figure 3. Surface dose rates of the original VSC-24 system (shield thickness is 78.1 cm) as a function of burnup and cooling time

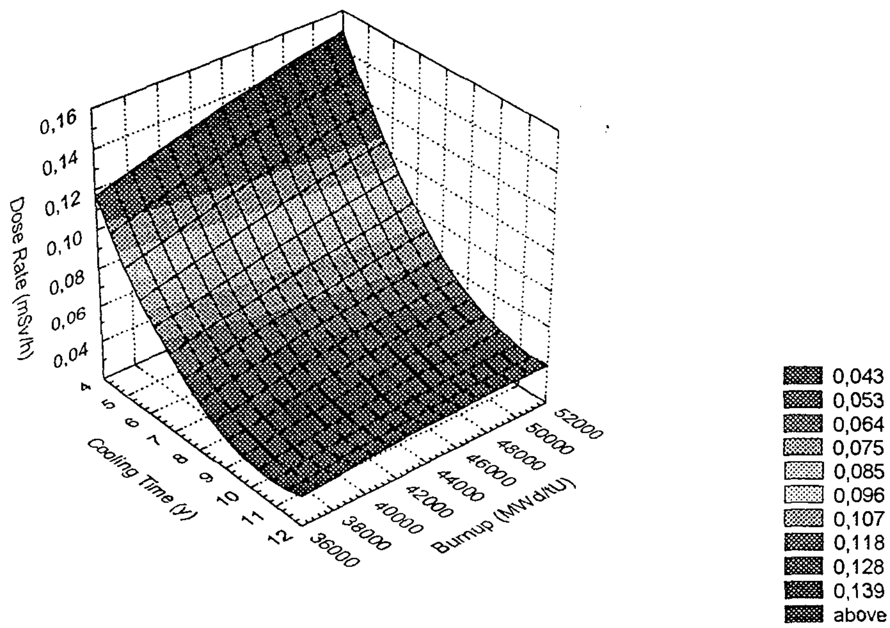

Figure 4. Surface dose rates of the modified VSC-24 system (shield thickness is 73.1 cm) as a function of burnup and cooling time

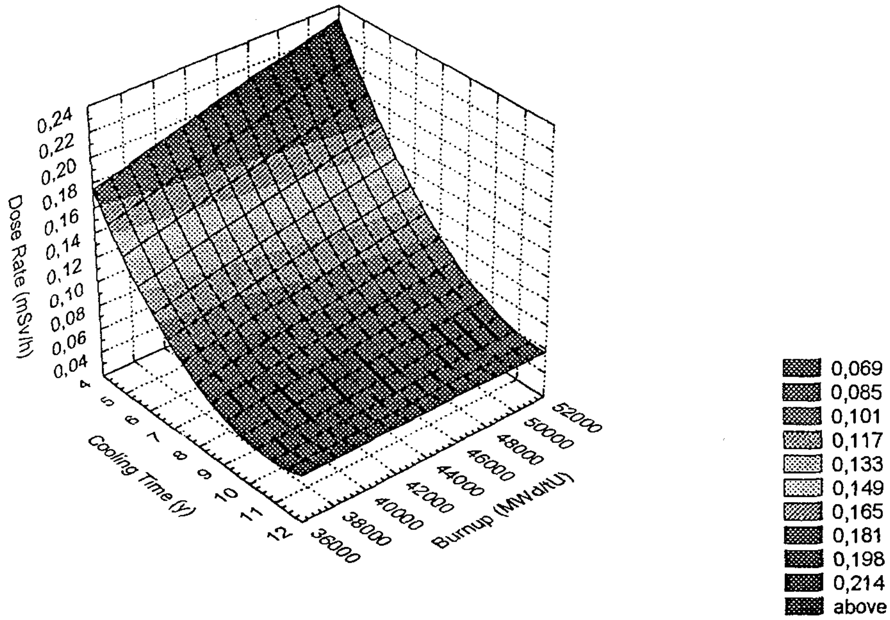

Figure 5. Surface dose rates of the modified VSC-24 system (shield thickness is 70.6 cm) as a function of burnup and cooling time

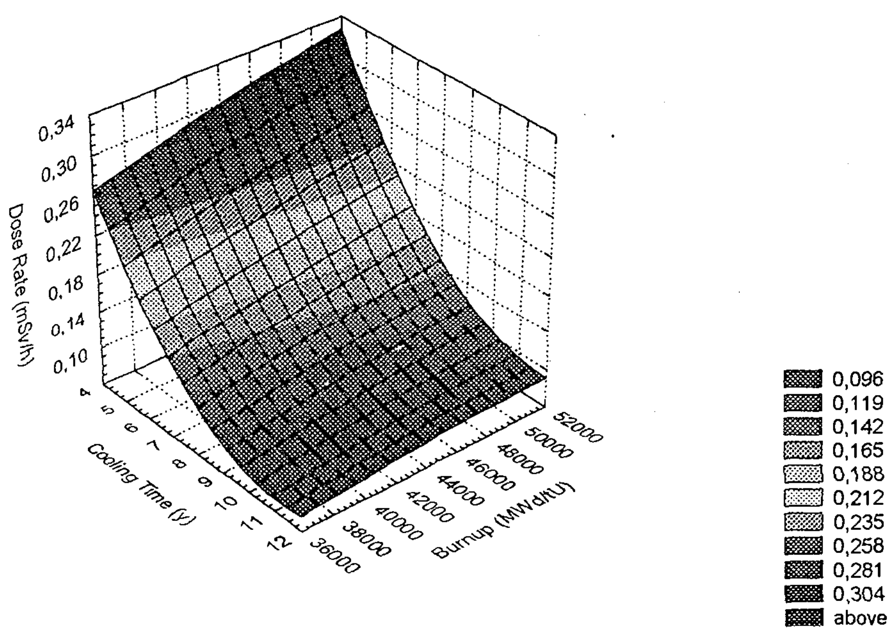

Figure 6. Surface dose rates of the modified VSC-24 system (shield thickness is 68.1 cm) as a function of burnup and cooling time