RISK ASSESMENT BASIS FOR VVER – 440 SPENT NUCLEAR FUEL

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ABSTRACT

The most problematic part of nuclear fuel cycle is its back end. Various high level waste management strategies are available or under development (final disposal of spent assemblies in deep repository, reprocessing, partitioning, transmutation,...). Application of any method is connected with production of characteristic high level waste (amount, radio-toxicity, form,...) as well as various risk level for the environment and mankind. Strategy selection should be based on risk analysis also.

The paper deals with assessment of risk, that is associated with VVER - 440 spent fuel inventory. In order to evaluate the risk, the accumulated amount of the radioactive inventory is calculated and the decay of the long-lived radionuclides is computed by ORIGEN code. Analysis is oriented on calculation of hazard indexes for assessing the relative hazards of actinides, toxic and long-lived radionuclides.

INTRODUCTION

The management of high-level radioactive waste has as its objective the isolation of hazardous radionuclides from the environment for a period of time long enough to ensure negligible risk. It is essential, therefore, that an index of radionuclide hazard must be available in order to permit an evaluation of the potential environmental risks from the presence of radionuclides in the biosphere. Further, in considering the risks associated with a mixture of hazardous radionuclides, this index of radionuclide hazard is useful to determine the relative contribution to the total hazard that individual or groups of radionuclide make.

Some of the variables of importance in determining of radionuclide environmental hazard are the quantities of individual toxic radionuclides, their relative toxicities, decay scheme and daughter products, and the time period of toxicity. An index of radionuclide hazard should include these aspects in appropriate way.

Various indexes of radionuclide hazard have been developed in the past. These indexes have the fault of being either inappropriate for long-term hazard assessment or incomplete in their formulation. In this paper a new relative radionuclide hazard index is applied to problem of radionuclide hazard analysis.

RELATIVE HAZARD INDEX

In order to provide an index of radionuclide hazard that is appropriate to problems of long-term management of radioactive material, a hazard index, H, is proposed. The hazard index is define for a given radionuclide in its general form by [1]:

$$H(t,d)=\sum_{j}\int_{t}^{t+d}\frac{A_j(t')}{MPI_j}dt' \qquad (1)$$

where the activity of radionuclide j as function of time is given by A, MPI_j is the maximum permissible annual intake of radionuclide j, and j is an index that permits summation over the given radionuclides and their radioactive daughters. H is seen to be functionally dependent on the integral limit parameters t and d. Physical meaning for these parameters are that t represents the time at which the radionuclides are released to the environment, and the period of time t to $t+d$ is the time interval of concern for the hazard calculation.

The value of d, the time period of concern, is determined by the nature of the problem being considered. Possible values for d might be 100 years, 1000 years, 100 000 years, or ∞. Once d has been selected, it is possible to evaluate H as a continuous function of t.

RELATIVE HAZARD ASSESSMENT OF VVER – 440 SPENT NUCLEAR FUEL

The first step for evaluation of relative radionuclide hazard indexes was calculation of VVER-440 spent fuel inventory in Slovakia. It means calculation of fuel assemblies with initial enrichments of 1.6 %, 2.4 %, 3.6 % and 3.82 % of ^{235}U, with the respective burn-up specific for each reactor cycle and with following cooling time up-to the year 2030 (the year when last unit is expected to stop) [2]. Results of these calculations are in Tab. 1. Used values of the time period of concern, were 100, 1000, 10 000 and 100 000 years after year 2030. All mentioned calculations were performed by the code ORIGEN [3].

These calculations determined the quantities of actinides and fission products produced in the reactor. The hazard indexes for assessment of the relative hazards of calculated quantities of radionuclides were estimated by fixing d and setting t equal to 0. The value of MPI_j for each radionuclide was evaluated using the international guidelines for occupational exposure (ICRP) [4]. Finally, the hazard indexes were determined by summing the values A_j/MPI_j and integrating in time.

The results of calculations are shown in Fig. 1 and Fig. 2. Note that the relative hazard index depends to half-time of decay of radionuclides. It means, that as d is allowed to increase, the values of $H(t,d)$ are decreasing. The Figure 1 is plot of the hazard indexes for U, Pu, Np, Am and Cm. Hazard indexes for Np, Pu and U are softly decreasing, but $H(t,d)$ for Cm is decreasing to minimum after 10 000 years. Figure 2 shows $H(t,d)$ for the fission products (^{90}Sr, ^{93}Zr, ^{99}Tc, ^{129}I and ^{137}Cs). The relative hazard indexes for selected radionuclides at various periods of concern are tabled (Table 2).

CONCLUSION

This paper provides calculations of hazard indexes for selected radionuclides from spent nuclear fuel. For their high relative hazard index, prevailing quantitative share in spent nuclear fuel and the longest half-time of decay, the most objectionable nuclides in the group of actinides are uranium, neptunium and plutonium, as can be seen in the Figure 1. In the group of fission products the same applies to radionuclides ^{93}Zr, ^{99}Tc and ^{129}I.

As can be seen in the Figure 1 and 2, hazard index for radionuclides ^{90}Sr, ^{137}Cs and Cm is decreasing to appropriate value approximately after 10 000 years. For others radionuclides is that mentioned period markedly longer. Account on this, it is very important to select the appropriate spent fuel and waste management strategy, which will be minimise mentioned risk.

REFERENCES

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[3] RSIC Computer Code Collection – manual, ORIGEN Isotope Generation and Depletion Code Matrix Exponential Method, Oak Ridge, ORNL 1991. 212 p.

[4] IAEA: International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources. SAFETY SERIES No. 115. Vienna, IAEA 1996. 352 p.

Table 1: Composition of VVER- 440 spent fuel in Slovakia in year 2030 - the most important radionuclides

Group	Radionuclides	Half-time of decay (years)	Quantity (kg)	Activity (TBq)
ACTINIDES	^{235}U	7.038E+08	1.843E+04	1.472E+00
	^{238}U	4.468E+09	1.972E+06	2.450E+01
	^{237}Np	2.140E+06	1.350E+03	3.517E+01
	^{238}Pu	8.774E+01	3.611E+02	2.285E+05
	^{239}Pu	2.411E+04	1.310E+04	3.003E+04
	^{240}Pu	6.550E+03	5.000E+03	4.202E+04
	^{241}Pu	1.410E+01	7.011E+02	2.726E+06
	^{242}Pu	3.763E+05	1.067E+03	1.549E+02
	^{241}Am	4.326E+02	2.375E+03	3.010E+05
	^{243}Am	7.370E+03	2.483E+02	1.832E+03
	^{244}Cm	1.811E+01	2.954E+01	8.834E+04
	Total value		*2.015E+06*	*3.418E+06*
FISSION PRODUCTS	^{90}Sr	2.850E+01	5.876E+02	3.027E+06
	^{93}Zr	1.500E+06	1.653E+03	1.566E+02
	^{99}Tc	2.100E+05	1.770E+03	1.125E+03
	^{129}I	1.570E+07	4.163E+02	2.716E+00
	^{137}Cs	3.017E+01	1.356E+03	4.333E+06
	Total value		*5.783E+03*	*7.361E+06*

Table 2: Relative hazard indexes for selected radionuclides at various periods of concern

Group	Radionuclides	H (t,100)	H (t,1 000)	H (t,10 000)	H (t,100 000)
ACTINIDES	^{235}U	3.13600E+19	3.19228E+19	3.68129E+19	5.24160E+19
	^{238}U	5.44521E+20	5.44521E+20	5.44521E+20	5.44549E+20
	^{237}Np	3.85990E+20	8.82547E+20	1.03362E+21	1.00441E+21
	^{238}Pu	5.88364E+23	5.41762E+20	2.17173E+02	0.00000E+00
	^{239}Pu	1.19917E+23	1.17022E+23	9.13117E+22	6.92844E+21
	^{240}Pu	1.67806E+23	1.52614E+23	5.87689E+22	4.21517E+18
	^{241}Pu	2.34714E+25	4.97200E+21	2.38653E+21	1.54846E+18
	^{242}Pu	6.45342E+20	6.44616E+20	6.34504E+20	5.40070E+20
	^{241}Am	1.75055E+24	4.17945E+23	5.62608E+19	3.83057E+16
	^{243}Am	9.10465E+21	8.36436E+21	3.59266E+21	7.66475E+17
	^{244}Cm	5.52662E+22	6.05655E+07	0.00000E+00	0.00000E+00
FISSION PRODUCTS	^{90}Sr	2.24186E+25	1.11486E+16	0.00000E+00	0.00000E+00
	^{93}Zr	1.42354E+23	1.42296E+23	1.41716E+23	1.36051E+23
	^{99}Tc	1.75761E+23	1.75251E+23	1.70193E+23	1.26987E+23
	^{129}I	2.46897E+19	2.46896E+19	2.46791E+19	2.45816E+19
	^{137}Cs	7.23336E+25	6.73337E+16	0.00000E+00	0.00000E+00

Figure 1: Comparison of hazard indexes for selected actinides

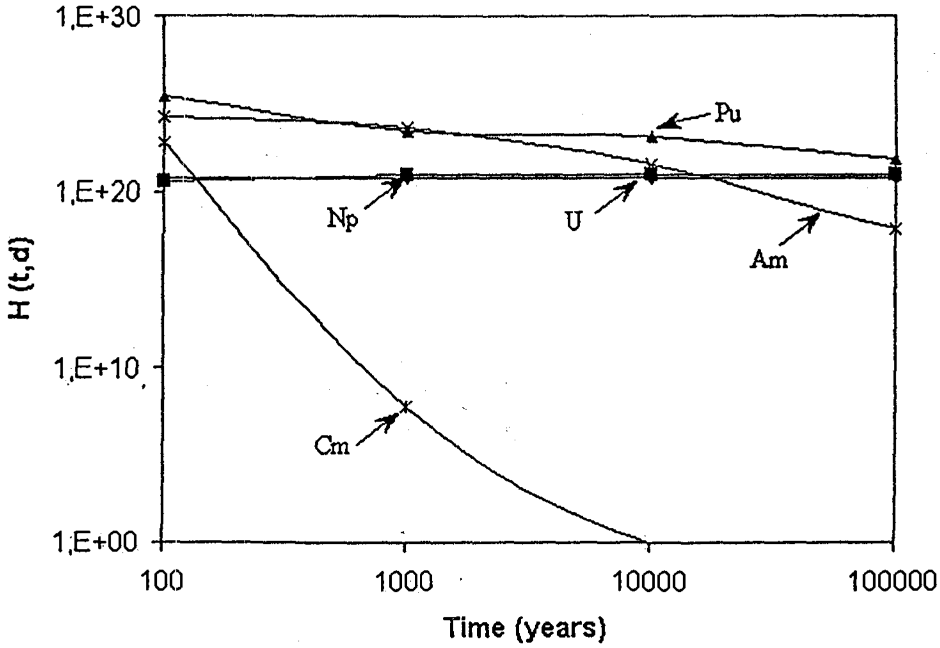

Figure 2: Comparison of hazard indexes for selected fission products