ENRICHMENT EFFECTS ON CANDU-SEU SPENT FUEL MONTE CARLO SHIELDING ANALYSIS

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Abstract: For CANDU type reactors, the most attractive solution trend in order to raise the discharge fuel burnup seems to be SEU and RU fuels utilization. The paper aims to study the effects induced by fuel enrichment variation on CANDU SEU spent fuel photon dose rates for a Monte Carlo shielding analysis. In order to obtain the spent fuel inventories and photon source profiles the ORIGEN-S code has been used. The shielding calculations have been performed by using the Monte Carlo MORSE-SGC code. Both codes are included in the ORNL's SCALE 5 programs package. A comparison for different fuel enrichments has been performed regarding both spent fuel characteristics and photon dose rates.

Key words: CANDU-SEU spent fuel, fuel enrichment, spent fuel transport, photon dose rate, shipping cask

1. INTRODUCTION

The promises for higher nuclear fuel utilization have lead to advanced cycles development need, but all the problems associated with radioactive waste have generated an increase in the interest for these fuel cycles.

Last decade, both for operating reactors and future reactor projects, a general trend to raise the discharge fuel burnup has been registered. The fuel burnup raise associated consequences are very important: spent fuel mass reduction for 1 MWh generated electric power; actinides mass significant reduction in the spent fuel; more rarely refueling, leading to impressing raises in installed capacity utilization; about 15%-35% reduction in costs associated with nuclear fuel, for 1 MWh generated electric power. For CANDU type reactor, one of the most attractive solutions is the use of SEU (Slight Enriched Uranium) fuel, the next logical step from natural uranium fuel in CANDU according [1]. By enriching natural uranium from 0.7% to between 0.9 and 1.2% in Uranium-235, fuel costs are lowered because less uranium and fewer bundles are needed to fuel the reactor. This in turn reduces the quantity of used fuel and its subsequent waste management costs.

AECL (Atomic Energy of Canada Limited), along with the Korea Atomic Energy Research Institute (KAERI), has developed CANFLEX (CANDU FLExible fuelling), an advanced fuel bundle design, to increase fuel performance and cost efficiency through improved heat transfer characteristics, and to maximize advanced fuel cycle options in CANDU reactors [2].

About 2 decades ago, Romania has opted for a heavy water nuclear power plant, CANDU6, the decision being based on the fact that the nuclear fuel and the heavy water needed for the NPP could be home-bred. Actually, Romania has only one nuclear power plant, Cernavoda NPP, equipped with 5 reactors PHWR CANDU 6 type, 705 MW(e) each. Unit 1 is in commercial operation since December, 1996,

Unit 2 is under construction, the rest of 3 units being under preservation stage. In the first 3 years of commercial operation, Cernavoda NPP Unit1 has given ~10% from the total electricity produced in Romania, this percent assuming to increase at around 17-20% after 2005 (with both Unit1 and Unit2 in operation).
The Romanian specialists have been analyzed many advanced fuel cycles, the estimations giving the best chance for SEU and RU fuel cycles application [3]. In the Institute for Nuclear Research Pitesti there is an active preoccupation, with promising evaluations, for the development of a fuel bundle CANDU-SEU [4] corresponding to the Canadian CANFLEX fuel project.
The nuclear energy world wide development is accompanied by huge quantities of spent nuclear fuel accumulation. Taking into account for the possible impact on the human and environment, in all activities associated to nuclear fuel cycle the spent fuel or radioactive waste characteristics must be well known.
According to IAEA data, more than 10 millions packages containing radioactive materials are annually world wide transported. Therefore, all the problems arisen from the maximum safe radioactive materials transport must be carefully settled. The regulations for safety radioactive materials transport must ensure the population, the authorized personnel and the environment protection against radiation exposures in a possible radioactive materials dispersion event. The protection/ safety must be oriented for maintaining individual doses, number of exposed humans and irradiation probability to the lowest values.

2. SHIELDING PROBLEM GENERAL DESCRIPTION

The source of radiation: A single spent fuel bundle, CANDU-SEU type with 43 Zircaloy rods, filled with SEU fuel pellets, has been used as source of radiation. Fuel characteristics and isotopic composition were those for CANDU-SEU fuel bundle developed in INR Pitesti [4]. The following enrichments (wt% in U235) have been used: 0.9 (case1), 0.96 (case2), 1.0 (case3), 1.2 (case4) and 1.5 (case5), respectively. After the discharge from the reactor core, the spent fuel is cooled down up to 10 years, in the NPP pools.

The shipping cask: All the geometrical and material data related to the shipping cask were considered according to the shipping cask type B model. The shipping cask prototype has been realized and tested in INR Pitesti [5].

The shielding problem theoretical model set-up: The fuel bundle was represented by 3 right, circular cylinders (1st for the central element and 7 fuel rods inner ring, the 2nd for the 14 fuel rods intermediate ring and the 3rd for the 21 fuel rods outer ring), containing a fuel, clad and structure materials homogenous mixture ("fuel"), with respect for the volume conservation [5].
The geometrical model for the shipping cask consists in right circular cylinders of shielding materials with a central cavity to accommodate the source region.

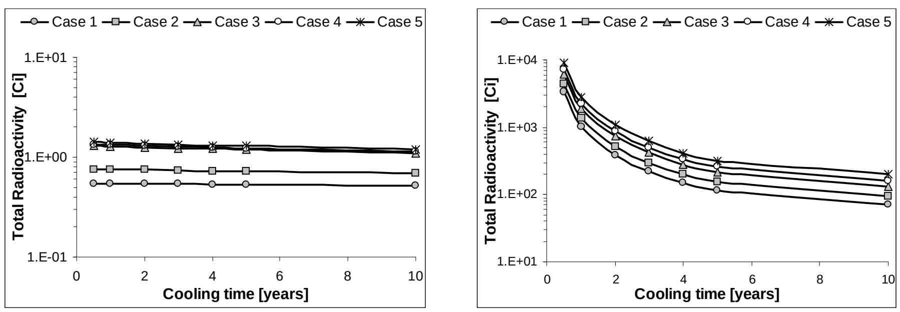
The shielding calculations: The photon dose rates calculations have been performed by means of Monte Carlo code MORSE-SGC. The shielding calculations were preceded by photon source calculations using ORIGEN-S code. In the shielding calculations, the (27n-18g) coupled nuclear data library and the ANSI standard flux-to-dose conversion factors were used. As regarding the Monte

Carlo simulation, 1000 bunches of 2000 particles each, have been generated.

3. SPENT FUEL ANALYSIS

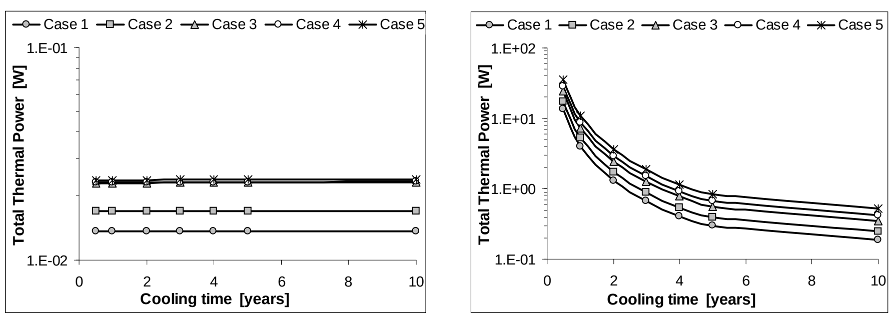
Fuel characteristics and isotopic composition were considered according to [4]. Data regarding the structural materials and nuclides isotopic composition from [6] have been used. For the shielding analysis have been used: a) 7 cooling times: 182 days, 1 year, 2 years, 3 years, 4 years, 5 years, 10 years; b) 4 measuring points: to the cask wall and in the air, at 0.5m, 1m and 2m distance from the shipping cask.

The spent fuel is characterized by the values of concentration, radioactivity, thermal and γ power. In Fig. 1, 2 and 3 the evolution of the spent fuel total values for radioactivity, thermal and γ power in actinides and fission products, during the cooling period, is shown. The studied cases are individualized.



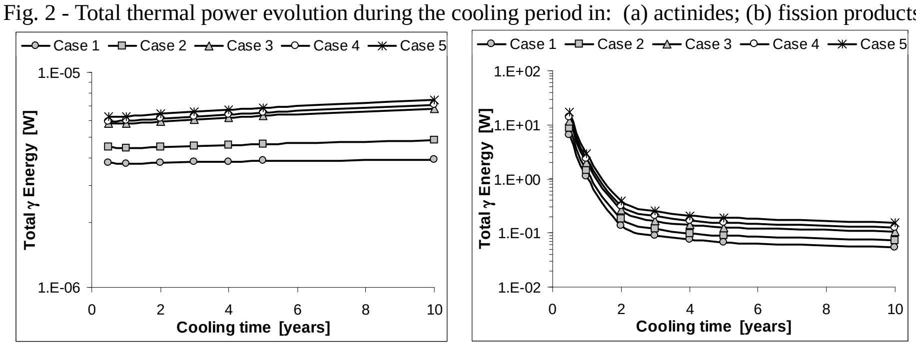
(a) (b)

Fig. 1 - Total radioactivity evolution during the cooling period in: (a) actinides; (b) fission pr5oducts



(a) (b)

Fig. 2 - Total thermal power evolution during the cooling period in: (a) actinides; (b) fission products



(a) (b)

Fig. [3]

Total γ energy evolution during the cooling period in: (a) actinides; (b) fission products

The photon dose rates to the cask wall and in air, at different distances from the shipping cask have been estimated. Their evolution during the cooling period is shown in the figure 4, for different measuring points and fuel enrichments.

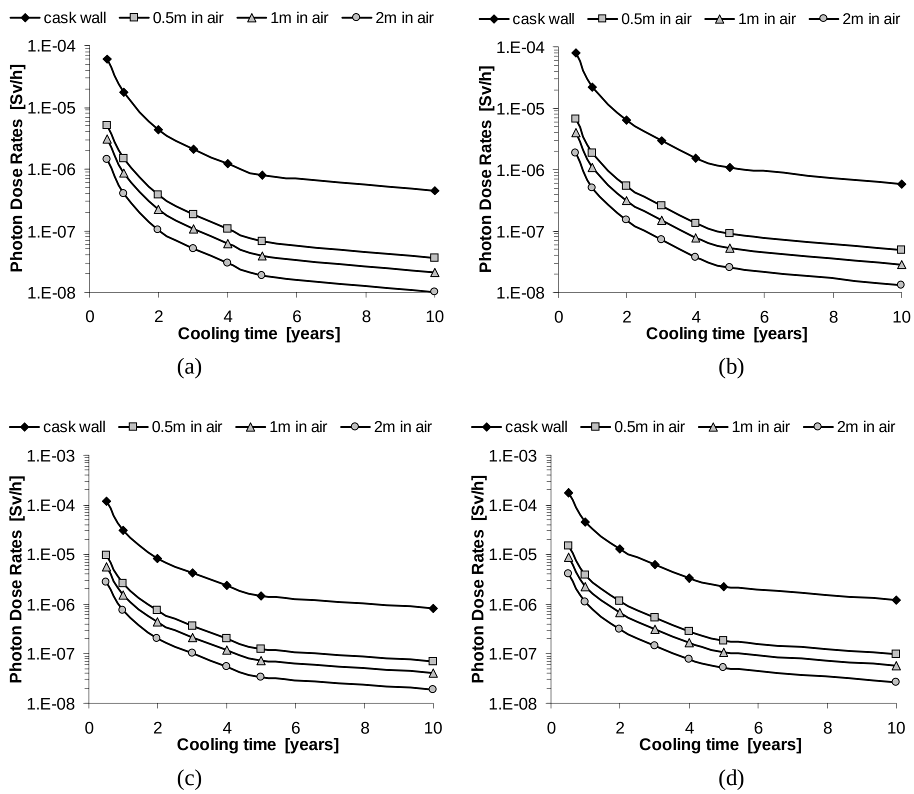


Fig. 4 - Photon dose rates evolution during the cooling period for:
(a) 0.9 wt% in U235; (b) 0.96 wt% in U235; (a) 1.0 wt% in U235; (b) 1.5 wt% in U235

4. CONCLUSIONS

Rise of SEU fuel enrichment from 0.9 to 1.5 wt% U235 leads to higher fuel burnup associated both with spent fuel and actinides mass reduction for 1 MWh generated electric power.

CANDU SEU fuel cycle produces a more radioactive spent fuel than the natural UO2 one [5], [7], [8]. The higher relative differences occur between 0.96 and 1.0 wt% in U235 fuel enrichment (26% in thermal and γ power, 40% in radioactivity).

For all cases, the estimated photon dose rates values for spent fuel transport are small, allowing a shipping cask safe manipulation. The dose rates to the cask wall decrease from 10^{-5} Sv/h (first year from discharge) to 10^{-6} Sv/h (after 2 years of cooling) and reach 10^{-7} Sv/h (after 10 years of cooling). At different distances from the shipping cask, the corresponding values were one or two degrees smaller.

As regarding the effect of fuel enrichment variation on the photon dose rates, the higher relative differences occur between 0.96 and 1.0 wt% U235:

- to the cask wall :32.7% (first year from discharge), 31.8% (after 2 years of cooling), 26.5% (after 5 years of cooling) and 30.9% (after 10 years of cooling).
- at 0.5m in air : 30.7% (first year from discharge), 28.9% (after 2 years of cooling), 26.7% (after 5 years of cooling) and 30.7% (after 10 years of cooling).
- at 1m in air : 30.5% (first year from discharge), 29.5% (after 2 years of cooling), 26.5% (after 5 years of cooling) and 29.9% (after 10 year of cooling).

For Cernavoda NPP Unit3, CANDU6 reactor is already an option. For the rest of 2 units, the principal candidate to CANDU 6 project seems to be another AECL project, namely CANDU NG (Next Generation) or CANDU ACR-700 (Advanced CANDU Reactor). Taking into account for the Romania future integration in European Union, another possibility is the option for an advanced PWR reactor. The opportunity to apply one of these solutions stands both in provability and desire to invest.

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