SEU43 Fuel Bundle Shielding Analysis during Spent Fuel Transport

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Abstract

The basic task accomplished by the shielding calculations in a nuclear safety analysis consist in radiation doses calculation, in order to prevent any risks both for personnel protection and impact on the environment during the spent fuel manipulation, transport and storage.

The paper investigates the effects induced by fuel bundle geometry modifications on the CANDU SEU spent fuel shielding analysis during transport. For this study, different CANDU-SEU43 fuel bundle projects, developed in INR Pitesti, have been considered.

The spent fuel characteristics will be obtained by means of ORIGEN-S code. In order to estimate the corresponding radiation doses for different measuring points the Monte Carlo MORSE-SGC code will be used. Both codes are included in ORNL's SCALE 5 programs package.

A comparison between the considered SEU43 fuel bundle projects will be also provided, with CANDU standard fuel bundle taken as reference.

KEYWORDS: SEU fuel, SEU43 fuel bundle, shielding analysis, shipping cask, photon dose rates

1. Introduction

In the Romanian Government policy, the nuclear power is considered as optimal solution for the national energy needs. In 2002, the Government decided to approve the Nuclear National Strategy for the next 50 years [1]. The Fundamental Objective specifies that between 2025-2050, Romanian Nuclear Power Plants must provide (20-40)% from the total electricity generated in Romania, with respecting both of the competitive costs conditions and the nuclear safety assurance at international agreed standards.

Romania has only one nuclear power plant, Cernavoda NPP, equipped with 5 reactors PHWR CANDU 6 type, CANDU 6 standard series - 706 MW(e) each. Unit 1 is in commercial operation since December, 1996, Unit 2 will be functional in 2007, and Unit 3 is under construction, the rest of two 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 (Fig. 1), this percent assuming to increase at around 16% after 2007 (with both Unit1 and Unit2 in operation) [2].

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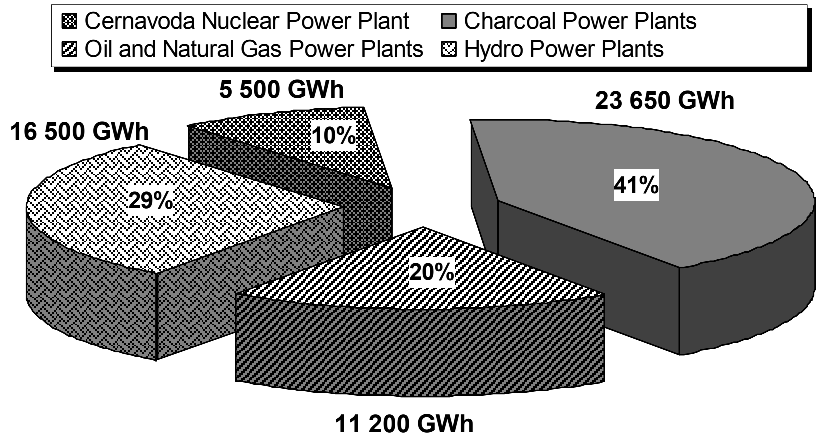
Figure 1: Coarse Power structure in Romania, end of 2004. [2]



In order to raise the discharge fuel burnup, Romanian specialists have been analyzed many advanced fuel cycles, the estimations giving the best chance for SEU and RU fuel cycles application [3]. In INR Pitesti there is an active preoccupation, with promising evaluations, for the development of a fuel bundle CANDU type SEU43 [4-6], similar to Canadian CANFLEX fuel bundle.

2. SEU43 Shielding Analysis

2.1 The Paper Objectives

The paper aims to investigate the effects induced by fuel bundle geometry modifications on the SEU43 spent fuel Monte Carlo shielding analysis applied to spent fuel transport after a defined cooling period in the NPP pools.

2.2 Shielding Problem General Description

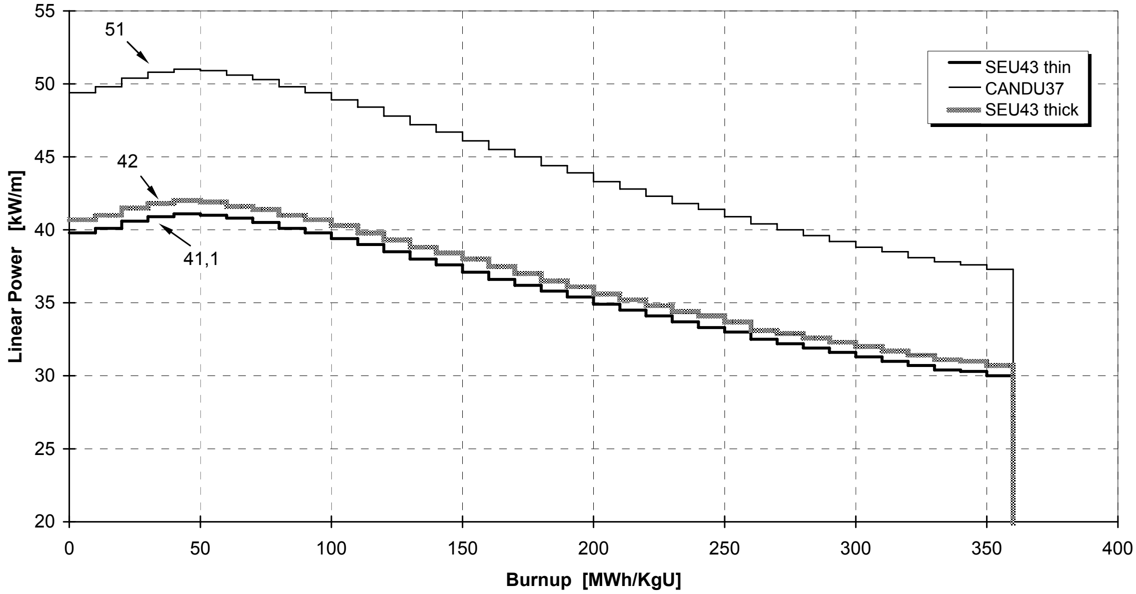
2.2.1 Source of Radiation

A single spent fuel bundle, CANDU standard with 37 Zircaloy rods, filled with natural UO_2 fuel pellets ("UNAT") and CANDU-SEU43 type with 43 Zircaloy rods, filled with SEU fuel pellets, for a 1.0 wt% in ^{235}U fuel enrichment, respectively, was used as source of radiation. After a residence period inside the reactor core of 235.26 days for natural UO_2 fuel and 462.53 days for SEU fuel, respectively, the spent fuel is cooled down up to 10 years, in the NPP pools.

In order to study the effects induced by modification in fuel bundle geometry, three different SEU43 fuel bundle projects, developed in INR Pitesti, have been used [4-6]. The SEU cases are identified as "SEU43a", "SEU43b" and "SEU43L" (twice longer as the other two projects).

The combination of low peak element ratings and a low and declining power boost envelope provide good confidence in the extended burnup fuel performance. Using ELESTRES code the SEU43 fuel element performance under nominal power was predicted as shown in Fig 2. As reference CANDU standard fuel element was used [5].

Figure 2: Linear Power history - SEU43 fuel elements against CANDU standard one (ELESTRES results). [5]



This prediction indicates that the SEU43 fuel with extended burnup will show good in-reactor performance as standard CANDU fuel do, because the fuel temperature (Fig. 3) and element internal gas pressure (Fig. 4) are far below the design criteria [5].

Figure 3: Fuel Center-line Temperature evolution during irradiation - SEU43 fuel elements against CANDU standard one (ELESTRES results). [5]

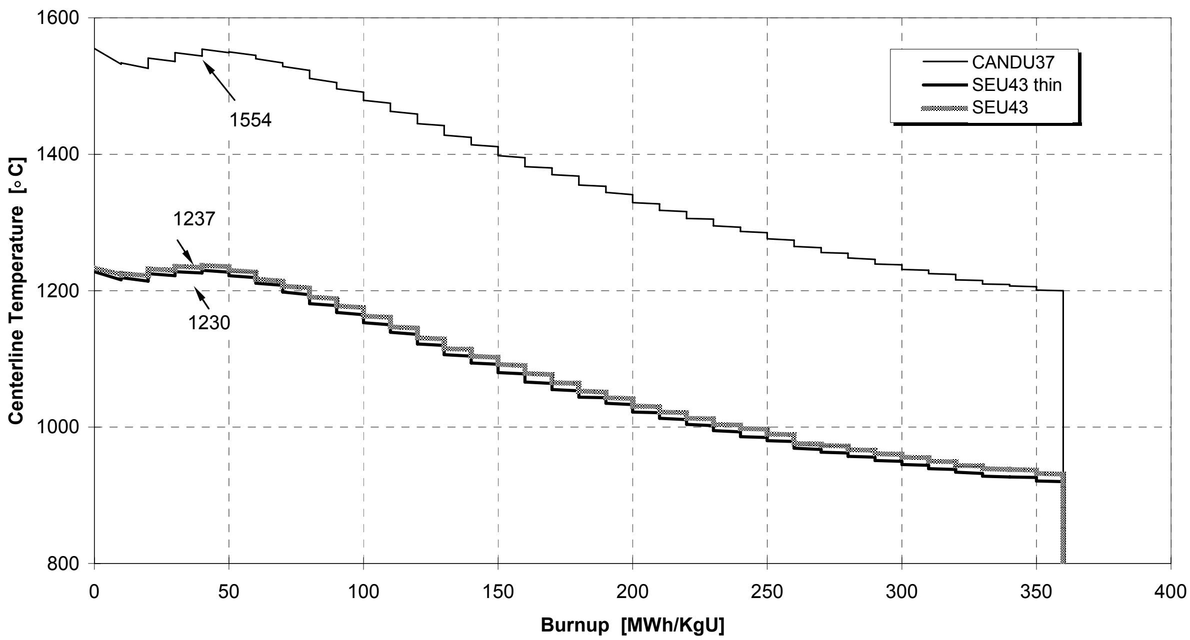
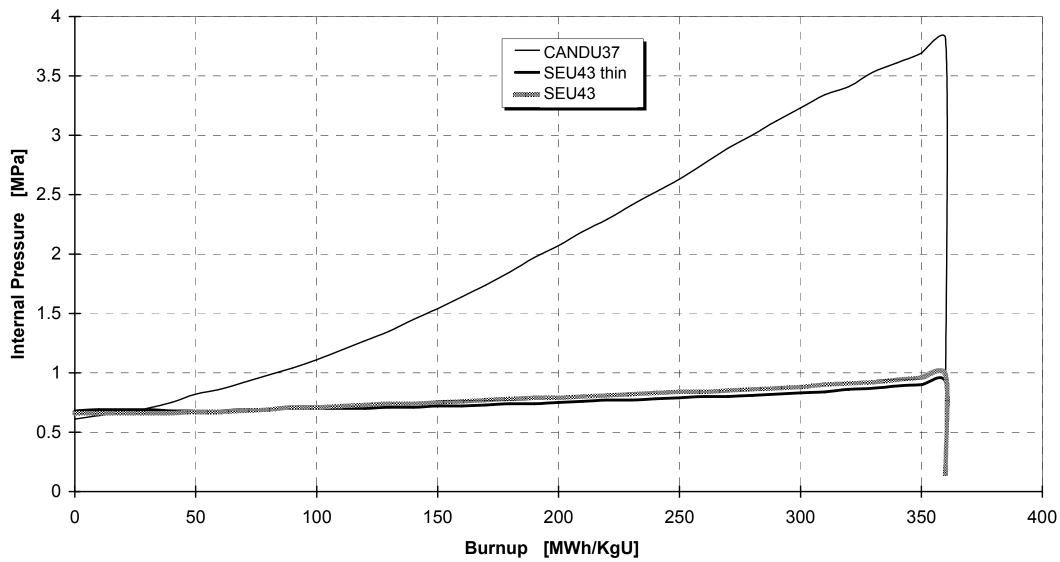


Figure 4: Internal Gas Pressure evolution during irradiation - SEU43 fuel elements against CANDU standard one (ELESTRES results). [5]



2.2.2 Shipping cask

All the geometrical and material data were considered according to the shipping cask type B model, whose prototype has been designed, manufactured and tested in INR Pitesti. The shipping cask authorization process is actually in progress.

2.2.3 The theoretical model set-up

The fuel bundle was represented by 3 right, circular cylinders (1st for the central element and the 6 or 7 fuel rods inner ring, the 2nd for the 12 or 14 fuel rods intermediate ring and the 3rd for the 18 or 21 fuel rods outer ring), containing a fuel, clad and structure materials homogenous mixture ("fuel"), with respect for the volume conservation. The geometrical model for the shipping cask consists in right circular cylinders of shielding materials with a central cavity to accommodate the source region [7].

2.2.4 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 ORIGEN-S photon source and spent fuel characteristics calculations. Both codes are included in ORNL’s SCALE 5 programs package received with individual license under ORNL-INR Pitesti collaboration agreement [8].

3. Shielding Analysis Results and Discussion

The spent fuel is characterized by the values of radioactivity, thermal power and γ energy. Fig. 5, 6 and 7 present the evolution of some spent fuel characteristics total values during the cooling period, for actinides and fission products. The comparison between SEU43 projects and the reference case, "UNAT", is also shown.

In order to study the evolution of spent fuel characteristics during the cooling period, the following cooling times have been considered: 185 days, 1 year, 2 years, 3 years, 4 years, 5 years and 10 years.

Figure 5: Total radioactivity evolution for actinides and fission products

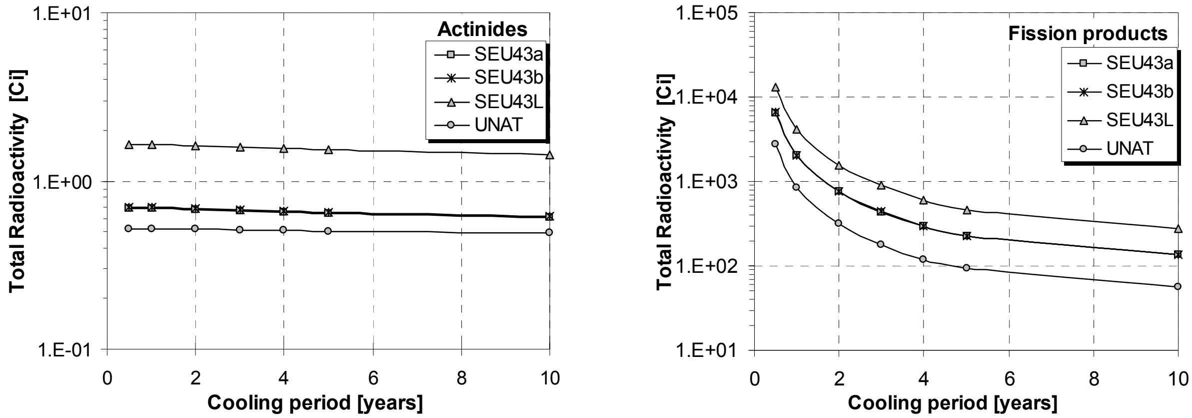


Figure 6: Total thermal power evolution for actinides and fission products

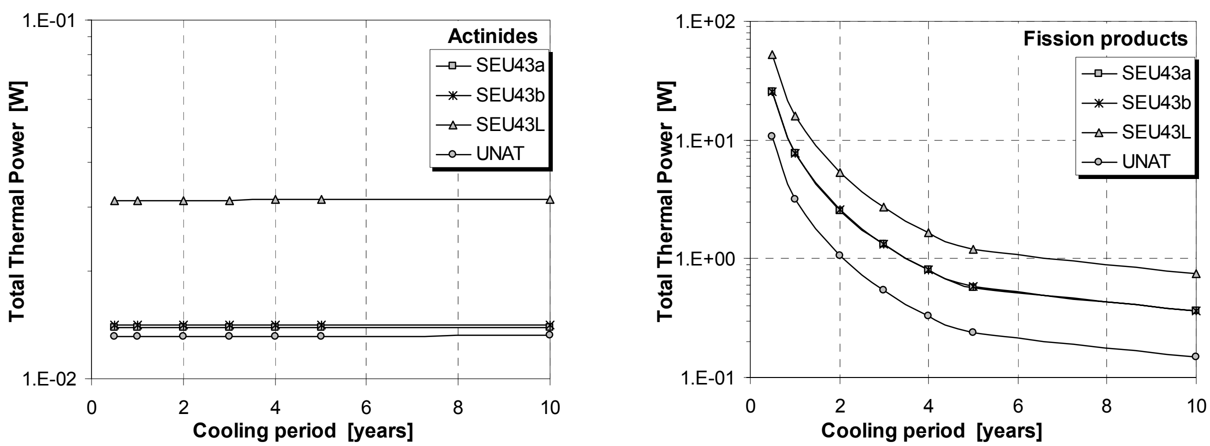
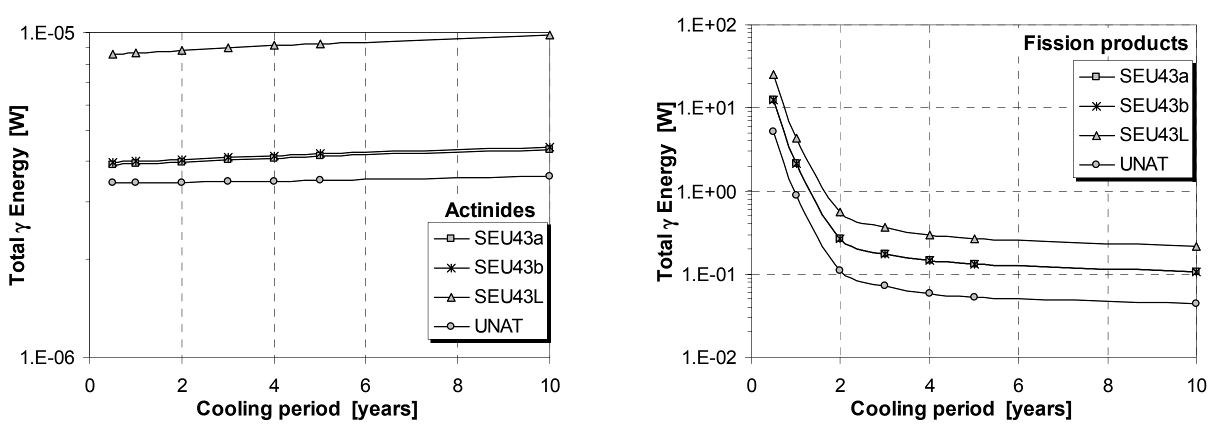


Figure 7: Total γ energy evolution for actinides and fission products

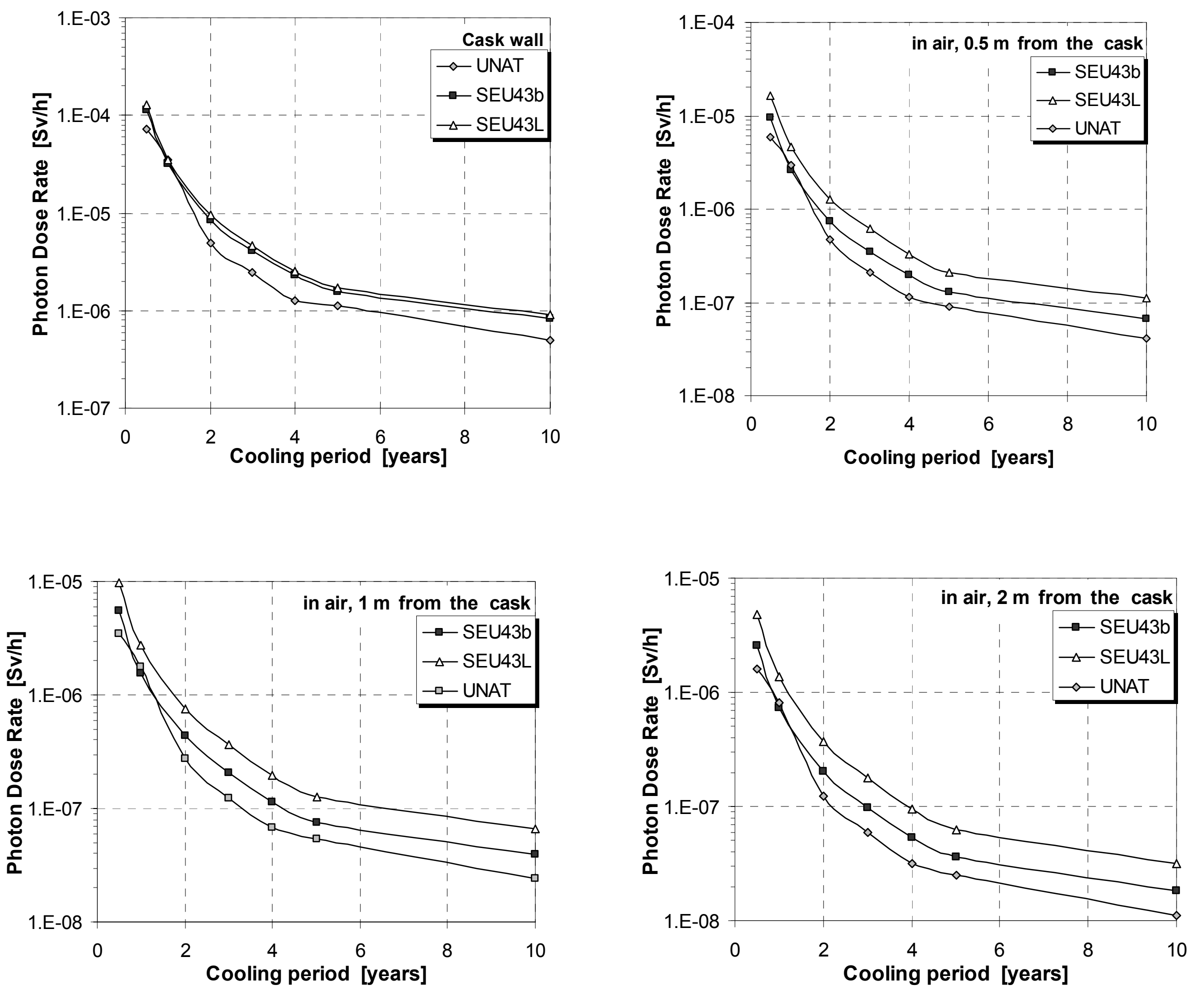


For some long life nuclides radioactivity relative differences have been calculated for the SEU43 fuel bundle projects. The nuclides corresponding to SEU43b were 1.64% more radioactive than the SEU43a ones. The SEU43L fuel bundle, twice longer than SEU43a and SEU43b, is characterized by an increase in the nuclides radioactivity, as follows: 50% for ^{90}Sr, 52% for ^{137}Cs, 56% for ^{239}Pu, 59% for ^{240}Pu, 62% for ^{241}Pu.

In order appreciate the radiological risk implied by the spent fuel transport inside the shipping cask, the following radiation dose rates measuring points have been considered: to the cask wall and in air at 0.5 m, 1 m and 2 m, respectively, distance from the shipping cask. The photon dose rates for the considered SEU43 fuel bundle projects and UNAT fuel bundle, respectively, have been estimated.

For the comparison SEU43a - SEU43b, the relative differences were less than 2%, for any considered measuring point. This is why, in the figure below (Fig.8) photon dose rates evolution during the cooling period only for the SEU43b and SEU43L projects against UNAT one was illustrated, considering different measuring points.

Figure 8: Photon dose rates evolution – SEU43b and SEU43L against UNAT



The estimated dose rates have safe values for the spent fuel cask transport and manipulation, both for the SEU43 and UNAT fuel bundle projects. According to radioactive material transport regulations [9,10] radiation level under routine conditions of transport shall not exceed 2 mSv/h to the cask wall, and 0.1 mSv/h at 2 m from the external surface of the conveyance.

4. Conclusion

SEU fuel leads to higher burnup than the natural UO_2 fuel. Meanwhile, for the same amount of electric energy generated, CANDU SEU fuel cycle produces a smaller, but more radioactive, weight of spent fuel (42.22% relative difference) than the natural UO_2 one [11,12].

The considered long life nuclides for SEU43b were 1.64% more radioactive than the SEU43a ones. For SEU43L, twice as long as the other two, nuclides radioactivity increase by (50 - 62)%.

The relative differences corresponding to the spent fuel characteristics for SEU43 fuel bundle geometry modification were less than 10% in SEU43a - SEU43b comparison; SEU43L brings a raise of (48 - 58)% in spent fuel characteristics.

As regarding spent fuel characteristics total values, UNAT-SEU43 comparison leads to the following relative differences:

- light elements: (26.4-27.5)% in radioactivity, (26.3-27.6)% in thermal power; (26.4-27.2)% in γ power:
- actinides: (31.0-33.4)% in radioactivity, (25.3-25.4)% in thermal power; (26.1-28.1)% in γ power:
- fission products: (41.5-42.2)% in radioactivity, (41.5-42.3)% in thermal power; (40.2-42.3)% in γ power.

The estimated photon dose rates for CANDU-SEU 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 degree smaller.

The relative differences were less than 2% in SEU43a - SEU43b comparison; SEU43L comparison with the other two fuel bundle projects leads to relative differences of (8 - 12)%. UNAT-SEU43 comparison leads to the following relative differences: (15-16)% (first year from discharge), (38-47)% (2-5 years of cooling), (42-44)% (10 years of cooling).

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