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National Cooperative for the
Disposal of Radioactive Waste

TECHNICAL REPORT 04-04

Comparison of ORIGEN2.1 with Selected Computer Codes

March 2004

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Abstract

Codes used to calculate radionuclide inventories have been compared with the aim of testing the predictive capability of the ORIGEN2.1 code. A suite of safety relevant radionuclides were examined and differences in the output of the codes were used as an indication of uncertainty in the ORIGEN2.1 output.

It was found that the activities of most of the safety relevant nuclides can be reliably predicted by ORIGEN2.1 calculations. However, for 9 out of the 64 radionuclides considered in this work, ORIGEN2.1 predicted activities that cannot be considered reliable. The origin of the discrepancies between the codes for these 9 nuclides will be further investigated by Nagra.

It was also shown that *the agreements and the deviations* noted for the safety relevant nuclides do not change significantly for a variation of the key parameters burnup, enrichment and power level.

The calculations give fair estimates of appropriate error bars that should be assigned to all of the obtained activities within ORIGEN2.1 calculations.

Zusammenfassung

Computerprogramme zur Berechnung von Nuklidinventaren wurden verglichen mit dem Ziel, die Zuverlässigkeit von ORIGEN2.1 Vorhersagen abzuschätzen. Für eine Reihe von sicherheitsrelevanten Nukliden wurden die mit verschiedenen Programmen berechneten Aktivitäten gegenübergestellt. Signifikante Differenzen wurden als ein Indiz für Unsicherheiten in den ORIGEN2.1 Resultaten gewertet.

Es stellte sich heraus, dass die Aktivitäten der meisten sicherheitsrelevanten Radionuklide durch ORIGEN2.1 Rechnungen zuverlässig bestimmt werden können. Für 9 der hier betrachteten 64 Radionuklide hingegen können die mit ORIGEN2.1 berechneten Aktivitäten nicht als zuverlässig angesehen werden. Die Ursachen für die gefundenen Abweichungen werden von der Nagra weiter untersucht.

Zudem ergab sich aus einer Variation der Schlüsselparameter Abbrand, Anreicherung und Leistungspegel dass sowohl *die für die sicherheitsrelevanten Radionuklide gefundenen Diskrepanzen als auch die gefundenen Übereinstimmungen* von diesen Schlüsselparametern weitgehend unabhängig sind.

Aus den hier präsentierten Ergebnissen können Radionuklid-spezifische Fehlerbalken extrahiert werden, die allen mittels ORIGEN2.1 Rechnungen bestimmten Aktivitäten von sicherheitsrelevanten Nukliden zugeordnet werden sollten.

Résumé

Une comparaison des codes utilisés pour le calcul des inventaires de radionucléides a été effectuée afin de tester la capacité du code ORIGEN2.1 à prédire les niveaux d'activité. Les différences dans les résultats obtenus sur une série de radionucléides significatifs ont mis en lumière les incertitudes inhérentes aux résultats obtenus avec ORIGEN2.1.

Il s'est avéré que les calculs effectués avec ORIGEN2.1 permettaient de prévoir de manière fiable l'activité de la plupart des radionucléides significatifs. Toutefois, pour 9 des 64 radionucléides pris en compte ici, les résultats obtenus avec ORIGEN2.1 ne peuvent être considérés comme fiables. L'origine des différences constatées entre les codes dans ces 9 cas fera l'objet de recherches complémentaires.

Il a également été démontré que les *correspondances et les différences* constatées pour les radionucléides significatifs restaient sensiblement les mêmes si l'on faisait varier les principaux paramètres (taux de combustion, taux d'enrichissement et niveau de puissance).

Ces calculs fournissent de bonnes estimations des marges d'erreurs qui devraient être appliquées aux niveaux d'activité obtenus avec ORIGEN2.1.

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1 Introduction and Objectives

The very first step in order to achieve safe disposal of radioactive waste consists of a good understanding of the waste, i.e., through a proper characterisation and classification of all waste packages. The main task to achieve this goal, especially for high level waste types, is to determine the radionuclide content of the spent fuel or the vitrified waste obtained from reprocessing.

There are various codes available to calculate radionuclide inventories of spent fuel, and each of these codes has its own advantages or disadvantages in comparison to other ones. Usually, as one would expect, the more sophisticated or complicated codes produce more accurate results. However, this benefit is often bought by significantly higher expenditure setting up the code input and for the amount of computing time needed.

The ORIGEN2.1 (Oak Ridge Isotope GENeration and depletion code) computer code is a widely used tool to calculate radionuclide inventories resulting from neutron irradiation of materials in a reactor. The original ORIGEN was developed at Oak Ridge National Laboratory in 1973 (Bell 1973), and, since then, has been distributed world-wide, updated and improved (Croff 1980, 1981). Hence ORIGEN2.1, released in 1991, is a well established code and has undergone a considerable amount of verification and validation work (i.e. Guenther et al 1988a, b, 1991a,b). Furthermore it is relatively straightforward to set up an input for ORIGEN2.1, and the code can be quickly executed on many computer platforms.

Radiological properties of irradiated materials are not easy to quantify because they depend on the initial material composition (including a detailed knowledge of the impurities), the irradiation history and both magnitude and spectrum of the neutron flux. However, in order to facilitate its use and to ensure fast execution, ORIGEN2.1 calculations use only a single neutron flux value, which corresponds to the core average flux derived from the power level of the reactor, and a library of single averaged cross sections, which are burnup-dependent and specific for each reactor and fuel type. These have been generated before by applying sophisticated reactor core model codes and therefore it must be ascertained which uncertainties must be attributed to predictions reached within ORIGEN2.1 calculations for the concentrations of those radionuclides, that are safety relevant with respect to a geological disposal of radioactive waste.

2 Inventories of Radionuclides from Various Computer Codes

2.1 Approach

In order to assess the power of ORIGEN2.1 to predict the activities of radioactive nuclides in the waste, its results will be compared with the output of three other computer codes using four different inputs, or reference cases. Of course, from the scientific point of view, the first choice would be to compare theoretical predictions with empirical data instead of other calculations, because various theoretical models might suffer from similar systematic shortcomings and may happen to produce coincident results, which, nevertheless, are in disagreement with the data (erroneous data in a decay or cross section library used by two different codes, for example, could lead to identical but nevertheless incorrect results). However, if data are not available, a comparison between codes certainly helps to identify those radionuclides that are difficult to predict, and, at least for the majority of the radioactive nuclides, should give a fair estimate of the relative error that must be attributed to the calculated concentrations.

2.2 Codes and Reference Files

Before comparing the output of different computer programs it is pertinent to itemise the main features (and differences) of the technical codes that are applied to determine the radionuclide composition of irradiated materials. These are given by:

- **Dimension:** The spatial flux distribution of neutrons or other activating particles can only be taken into account by multidimensional codes (2D or 3D), which therefore usually constitute the most sophisticated tools to describe build-up, decay and processing of radioactive materials. But, as the geometry of, for example, a reactor core, has to be set up in the input, these codes are generally more difficult to use. They also usually require long computing times.
- **Cross section type:** Cross sections for neutron induced reactions on nuclides depend on the energy of the incoming neutron and may show sharp and strong resonances, especially in the epithermal region. While continuous or point-wise cross section data take this accurately into account, multi-group cross section data only include values averaged over several energy regions. The simplest and, with respect to computing time, fastest, treatment consists in using just one effective neutron cross section that has been generated by condensing neutron energy spectra calculated by multidimensional codes with point-wise cross section data.
- **Cross section library:** There are various groups that compile and evaluate cross section data and provide corresponding libraries to the scientific community. The libraries that are currently used by most of the technical codes are: JEF-2.2 (Nordborg 1994), ENDF/B-V, ENDF/B-VI (NNDC 2002), and JENDL-3.3 (Shibata 2002).
- **Decay library:** Half-lives and branching ratios for the decay modes of radionuclides constitute another important input to calculations and are subject to regular revisions. Thus it should be ascertained that the decay library used by a code is up to date.
- **Particles included:** While simpler codes only consider neutrons and photons, more sophisticated codes also take into account electrons, protons, alpha particles, etc.
- **Physical processes included:** In the case of photon physics, for example, the various codes may incorporate the following processes in more or less detail: coherent and incoherent scattering of electrons, pair production, Bremsstrahlung, photoelectric absorption and fluorescence.

- **Number of nuclides included:** The number of nuclides that are included in the reaction network and in the libraries varies for the codes.
- **Verification and validation:** Codes also differ with respect to the amount of verification and validation that has been carried out.
- **Handling:** Installation of a code on a computer, setting up the input and evaluating the output (graphic output capabilities?) can be difficult.
- **Computing time:** Typical running times of a code can vary between a few seconds to many hours.
- **Special features:** The physical laws that determine the propagation and reactions of particles are usually (integro)differential equations that can be solved under various approximation schemes and by application of differing analytical or numerical methods. Such special features are described in the individual documentation of the technical codes.

For the comparison performed here, the following four codes, which represent a sample of the available codes covering the spectrum from "simple" to sophisticated, have been chosen:

- **ORIGEN2.1 (Croff 1981):** ORIGEN2.1 is relatively straightforward to operate and the reference cases specified below could be executed in a couple of seconds on a standard PC running under the Windows operating system. Using point-depletion analysis for various generic reactor types, ORIGEN2.1 calculates the build up and decay of nuclides in nuclear materials. A larger number of reactor-type/fuel-type libraries that have been produced previously (within reactor core models that provide a multi-group neutron energy spectrum) can be applied. Multi-group neutron cross sections were condensed with these neutron energy spectra to produce the weighted spectrum, i.e., one-group cross sections. Thus there are several cross section libraries provided with the ORIGEN2.1 code, each of which is specific for a reactor and fuel-type and, furthermore, only covers a limited range of burnups. Therefore the uncertainty of radionuclide inventories calculated with ORIGEN2.1 may be high for cases where either no cross section library is available for the specific reactor type considered, or the burnup exceeds the library maximum.
- **ORIGEN-ARP (SCALE 1995):** ORIGEN-ARP (Advanced Rapid Processing) is a graphical user interface (GUI) to easily set up ORIGEN-S depletion and decay cases. Within ORIGEN-ARP new ORIGEN-S cross section libraries can be generated by interpolation of existing cross section data. This interpolation can be done for the parameters burnup, enrichment, and moderator density. The basic multi-burnup libraries (one for each enrichment/moderator density combination) have been generated by the SASH module, which is a part of the SCALE computational system. ORIGEN-S itself, like ORIGEN2.1, is an updated version of the original ORIGEN code, and, in order to describe generation and depletion of the nuclides, retains the application of the matrix exponential method to solve the nuclide rate of change balance equations. One of the primary objectives in developing ORIGEN-S was to enable calculations to utilise multi-energy group neutron fluxes and cross sections in any group structure.
- **OCTOPUS (Klostermann 1996):** The OCTOPUS code system uses the MCNP4C3 code (Briesmeister 2000), (Hendricks 2001) for the neutron spectrum calculations and the ORIGEN-S code (Hermann 1989) for the burnup calculations. The cross section data employed in both calculations are based on the European JEF-2.2 library (Hogenbirk 1995), (Hoogenboom 1997).
- **BOXER (Paratte 1996):** The BOXER code is one out of four components of the ELCOS (Eir-Lwr-COde System) package for the stationary simulation of light water reactor cores, which has been developed at the former Swiss Federal Institute for Reactor Research EIR

(now known as PSI - the Paul Scherrer Institute). BOXER uses a grouped, or in the resonance range point cross section library previously generated from a basic library in ENDF/B-format (by the ETOBOX code, which is the first component of ELCOS). BOXER has a modular structure and performs two-dimensional calculations of LWR configurations, represented by a x-y mesh grid. The neutron flux distribution can be calculated with a diffusion or a transport module. A special depletion module called MULFIP was build into the BOXER code in order to allow the time evolution of up to 1000 fission products and light nuclides, furthermore up to 1000 heavy nuclides. This extension turned out to be necessary, because several radioactive nuclides with low neutron cross sections have been found not to play a significant role in a reactor. These must be included for a proper characterisation of radioactive waste, because they have a high radiotoxicity and/or contribute to the thermal power of the waste. Finally, some of these radionuclides are produced in complicated decay chains involving non-radioactive nuclides (i.e., following further irradiation of stable nuclides).

The features of the applied codes are summarised in Table 1:

Table 1: Main features of the 4 codes considered in the comparison (light = light elements, act = actinides, fp = fission products).

Feature	**ORIGEN2.1**	**ORIGEN-ARP**	**OCTOPUS**	**BOXER**
Dimension	0	0	3	2
Cross section type	single group	multi-group	multi-group	multi-group
Cross section library	ENDF/B-V	ENDF/B-V	JEF-2.2	ENDF/B-V and JEF-2.2
Decay library (year of revision)	2002	1991	1991	2002
Number of nuclides included in the transition libraries	700 light 132 act 880 fp	689 light 129 act 879 fp	689 light 129 act 879 fp	624 light 144 act 768 fp
Verification and validation	very good	good	good	very good
Handling	easy	very easy	moderate	moderate
Computing time on a standard PC	seconds	seconds	hours	minutes

The calculations were performed for four reference inputs, which are listed in Appendix A. The reference cases represent a spectrum of the key parameters burnup, power and enrichment and are summarised and labelled in the Table 2:

Table 2: List of key parameters represented in the reference cases.

Reference Case	Burnup ($GWd(t_{IHM})^{-1}$)	Power ($MW(t_{IHM})^{-1}$)	Enrichment (%)
JNFL	45	38	4.5
BNFL	33	27.1	3.35
COGEMA	33	30	3.5
TVF	28	35	4.0

In all four reference cases, it is assumed that the burnup was achieved within just one irradiation cycle and the input of all four codes was set up accordingly.

Some options available within the ORIGEN2.1 and ORIGEN-ARP codes were adapted to these reference cases, and these are also specified in Appendix A.

2.3 Results

The results obtained from the ORIGEN2.1 calculations are presented in Appendix B. In Tables B.1, B.2, B.3, and B.4, respectively, the activities of the radionuclides in the fuel are given for the reference cases 1 to 4 from Table 2 and for 9 decay times: directly after discharge and after a decay of 1, 3, 10, 100, 1,000, 10,000, 100,000 and 1,000,000 years. The list of radionuclides is based on the list of safety relevant nuclides given in Appendix 5 of (Nagra 2002)[1] and comprises in total 64 radionuclides: 36 light elements and fission products and 28 actinides. The last three values at the bottom of each list, labelled "Total", "Alpha", and "Beta/Gamma", state the total activity of the fuel, split up in the contributions from α-decays or β- plus γ-decays, respectively.

Considering the approximations included in ORIGEN2.1 (as mentioned in section 2.2), it is obvious that several of the entries in Tables B.1, B.2, B.3, and B.4 should not be accepted uncritically, but that an error must be attributed to them. In order to obtain a first estimate for the magnitude of error corresponding to each entry, the ORIGEN2.1 results are compared with the results of the 3 other codes in Appendix C. In the four Tables C.1, C.2, C.3, and C.4, respectively, the activities of the radionuclides obtained with the various codes are compared for the reference cases 1 to 4 (JNFL, BNFL, COGEMA, TVF) of Table 2. While the 2nd, 3rd, 4th, and 5th column simply present the activities at the time of discharge, columns 6-8 give the ratios of the values of the three other codes to the ORIGEN2.1 result, in order to allow for easy comparison. For the purpose of classifying the deviations, the entries in the last three columns have been coloured following the scheme:

- if the activities agree within 30 percent of the ORIGEN2.1 result, i.e., in case the ratio R lies in the range $0.7 \le R \le 1.3$, the number is printed in black,
- if the disagreement is greater than 30 percent, but smaller than a factor of 2 (which is $0.5 \le R < 0.7$ or $1.3 < R \le 2.0$), the entry is given in blue,
- deviations between a factor of 2 and 10 ($0.1 \le R < 0.5$ or $2.0 < R \le 10.0$) are printed in red,
- differences greater than one order of magnitude are highlighted in magenta ($R < 0.1$ or $R \ge 10.0$).

[1] This list is relevant to a deep geological repository for vitrified high-level waste, spent fuel and MOX (mixed-oxide fuel). As such, it includes more radionuclides than would be the case for a vitrified high-level waste repository as considered in (JNC 2000), but has the advantage of covering most radionuclides which will be of eventual interest to the Japanese national programme when responsibility for spent fuel and MOX is defined.

2.4 Discussion

First, it is important to note that the differences in the last three lines of Tables C.1, C.2, C.3, and C.4 (namely total activity, α-activity and β-γ-activity) are not greater than 30 percent, demonstrating that there is general agreement between all codes. This can be taken as an indication of the fact that ORIGEN2.1 calculations predict the total activity of spent fuel, for the range of key parameters (burnup, power and enrichment) considered here, very well. Furthermore, as the sums of the activities from α-decays as well as β- plus γ-decays match, the activities of those radionuclides that give the dominant contributions to both sums must roughly be in agreement, too. (Otherwise the sums would not happen to match for all reference cases). This can be verified by looking at the ratios given in Tables C.1, C.2, C.3, and C.4 for the radionuclides with the highest activities, which all turn out to be in fair agreement. In detail, the radionuclides that dominate the total activity from β- plus γ-decays are: ^{106}Ru, ^{134}Cs, ^{147}Pm, ^{241}Pu, ^{137}Cs, ^{90}Sr, ^{125}Sb, ^{85}Kr, ^{154}Eu, ^{155}Eu. Those that dominate the total activity from α-decays are: ^{238}Pu, ^{244}Cm, ^{240}Pu, ^{239}Pu, ^{241}Am.

A comparison of the "colour patterns" in Tables C.1, C.2, C.3, and C.4 shows that they are very similar, which means that the differences in the predicted activities of the radionuclides are universal for the reference cases, i.e., they do not depend strongly on the values of the key parameters. Hence, in the following the differences in all tables can be examined by just discussing the deviations in Table C.1, referring to the JNFL reference case.

Among the 64 radionuclides listed in Table C.1, there are 28, for which all 4 codes give essentially identical results (all entries in the last 3 columns are black). These are: ^{3}H, ^{36}Cl, ^{63}Ni, ^{79}Se, ^{87}Rb, ^{90}Sr, ^{99}Tc, ^{106}Ru, ^{107}Pd, ^{126}Sn, ^{129}I, ^{134}Cs, ^{135}Cs, ^{137}Cs, ^{147}Sm, ^{154}Eu, ^{226}Ra, ^{228}Th, ^{232}Th, ^{234}U, ^{235}U, ^{236}U, ^{238}U, ^{237}Np, ^{239}Pu, ^{240}Pu, ^{241}Pu, and ^{242}Pu. This indicates that the activities of these nuclides, as predicted by ORIGEN2.1 calculations, are well reproduced by the other 3 codes.

Next, there are 14 radionuclides for which ORIGEN2.1 and two of the three other codes give consistent activities, and just one of the other codes (in most of the cases it is ORIGEN-ARP) shows a discrepancy smaller than a factor of 2 (two black and one blue number): ^{41}Ca, ^{59}Ni, ^{93}Zr, ^{93}Nb^{m}, ^{125}Sb, ^{147}Pm, ^{151}Sm, ^{152}Eu, ^{230}Th, ^{232}U, ^{238}Pu, ^{242}Am^{m}, ^{243}Am, and ^{244}Cm. In these cases it can be assumed, especially as most of the "blue numbers" have values corresponding to deviations smaller than 50 percent, that the activities of these nuclei obtained by ORIGEN2.1 calculations are quite reproducible too.

There are 6 radionuclides in Table C.1 for which more than 2 blue entries can be found: ^{55}Fe, ^{94}Nb, ^{233}U, ^{241}Am, ^{245}Cm, and ^{246}Cm. Most of the ratios listed for these 6 nuclides have values around 1.5, indicating that the activities of these nuclei are underestimated by ORIGEN2.1 calculations. In order to obtain a conservative estimate for the activities of these radionuclides, the ORIGEN2.1 results could be multiplied by a factor of 2. As only the activities of the radionuclides in the fuel have been compared, it is impossible to say at this point, whether a similar correction factor of 2 should be applied to, for example, the activity of ^{55}Fe in the structural material.

Finally, for the remaining 16 radionuclides not yet listed significant discrepancies between the results of the codes exist (namely: ^{10}Be, ^{14}C, ^{60}Co, ^{85}Kr, ^{93}Mo, ^{108}Ag^{m}, ^{113}Cd^{m}, ^{121}Sn^{m}, ^{155}Eu, ^{166}Ho^{m}, ^{210}Pb, ^{210}Po, ^{228}Ra, ^{227}Ac, ^{229}Th, and ^{231}Pa), and these differences will now be discussed in detail:

- For 5 out of the 16 nuclides essentially only one out of the four codes gives a significantly different result. For ^{60}Co and ^{113}Cd^{m}, the OCTOPUS code underestimates the activities by a factor of more than 100, while it overestimates the activity of ^{228}Ra by 3.46. The nuclides ^{227}Ac and ^{231}Pa are overestimated by ORIGEN-ARP by a factor of 2.80 and 2.02, respectively. Assuming that the BOXER code is the most sophisticated and reliable code of the 4 codes considered here, it is assumed that the deviations for these 5 radionuclides are due to failures of the OCTOPUS code (^{60}Co, ^{113}Cd^{m} , and ^{228}Ra) and ORIGEN-ARP code (^{227}Ac and ^{231}Pa). Thus it may be taken that the ORIGEN2.1 results for the corresponding activities of these radionuclides are comparable.

- For ^{155}Eu and ^{229}Th, ORIGEN2.1 seems to overrate the activities by a factor of roughly 2, which, if conservative estimates are required, is not a significant difference.
- The activities of the 3 radionuclides ^{14}C, ^{93}Mo, and ^{210}Po seem to be underestimated by ORIGEN2.1 by factors between roughly 2 and 4. Therefore these ORIGEN2.1 results should not be considered reliable. However, by correcting with the corresponding factors (between roughly 2 and 4) one might still end up with a reasonable estimate for the activities. The application of such a correction factor will be justified in section 3.
- At least for the 6 radionuclides ^{10}Be, ^{85}Kr, ^{108}Ag^{m}, ^{121}Sn^{m}, ^{166}Ho^{m}, and ^{210}Pb no systematic trend can be obtained from the ratios that would allow a reasonable correction of the ORIGEN2.1 results. Therefore the activities of these radionuclides derived from ORIGEN2.1 calculations should be considered highly unreliable.

Finally, it is of note that the differences found with respect to the radionuclides ^{14}C and ^{85}Kr will not pose a problem if the spent fuel is reprocessed and only the vitrified waste is returned to the producer as under current international contract with BNFL and Cogema[2]. In this case these nuclides (as well as ^{3}H and ^{36}Cl) will be lost during reprocessing and will not appear in the glass[3].

2.5 Summary

For a list of 64 safety relevant nuclides, it was found, by comparison with the results of 3 other codes, that ORIGEN2.1 is, for the majority of them, an adequate tool to derive their activities within a fuel depletion calculation. However, for 9 of the radionuclides, considerable differences in the activities predicted by the various codes were noted leading to the conclusion that their activities obtained with an ORIGEN2.1 calculation should not be considered reliable. These radionuclides are: ^{10}Be, ^{14}C, ^{85}Kr, ^{93}Mo, ^{108}Ag^{m}, ^{121}Sn^{m}, ^{166}Ho^{m}, ^{210}Pb, and ^{210}Po. The origin of the discrepancies between the codes for these 9 nuclides will be further investigated by Nagra.

With respect to ^{14}C, ^{93}Mo, and ^{210}Po, a reasonable estimate for their activities may still be reached by correcting with factors (between roughly 2 and 4) that can be extracted from the code comparison performed in this work.

The activities predicted by ORIGEN2.1 for the 6 radionuclides ^{10}Be, ^{85}Kr, ^{108}Ag^{m}, ^{121}Sn^{m}, ^{166}Ho^{m}, and ^{210}Pb should be considered highly unreliable and should not be used in a safety analysis.

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[2] Of course, this will no longer be the case when JNFL starts up their domestic reprocessing facility at Rokkasho.

[3] Such high ^{14}C etc. wastes already exist in Japan, derived from JNC's pilot vitrification plant at Tokai.

3 The Effect of Input Parameters on ORIGEN2.1 Results

3.1 Approach

In chapter 2 the nuclide activities determined by four different codes (ORIGEN2.1, ORIGEN-ARP, OCTOPUS, and BOXER) were compared in order to identify those radionuclides that are difficult to predict. This comparison was performed for various inputs or reference cases, and the scattering of the results was used to estimate the relative error that must be attributed to the calculated concentrations. Table D.1 in Appendix D shows the nuclide activities that were obtained from the 4 codes reference case 1, Table 2 (JNFL), which is specified in Tables A.1 and A.2 in Appendix A. In order to allow for an easy comparison, the last three columns in Table D.1 give the *ratios of the results of the first three codes to the activities predicted by BOXER*. Note, that the BOXER code is considered to be the most sophisticated and reliable of the 4 codes applied, which to a large extent is borne out by the ratios given in the last three columns of Table D.1. Here, clear contradictions between BOXER results, as opposed to the predictions of the other 3 codes, cannot be found, and, in the case of large scattering of the activities obtained for any given radionuclide, BOXER tends to provide the most conservative estimate. For these reasons, BOXER is the standard tool applied by Nagra to determine the radionuclide content of spent fuel, vitrified waste and activated reactor components.

The approach taken in the following to assess the predictive capabilities of ORIGEN2.1 will be to compare its results only with the output of the BOXER code, but for a higher number of input files. The input files will cover a range of the key parameters burnup, enrichment, and power level in order to study and compare the systematic trends that both codes predict for the concentrations of radionuclides as a function of the key parameters. This approach was chosen for the following reasons:

- In chapter 2 it was found that for a high number of the safety relevant nuclides ORIGEN2.1 constitutes an adequate tool to derive their activities for a set of standard reference inputs. However, the question arises whether ORIGEN2.1 predictions for these radionuclides are still reliable for extreme values of the key parameters, e.g., for a high burnup.
- The results of chapter 2 also suggested that, for some of the radionuclides whose concentrations were underestimated by ORIGEN2.1 calculations, a reasonable estimate can be achieved by multiplying the activities with a phenomenological correction factor. However, this only works, if the correction factor does not vary significantly with the values of the key parameters.

3.2 Codes and Variations of Input Parameters

The main features (and differences) of technical codes that are applied to determine the radionuclide composition of irradiated materials have been outlined in section 2.2, where also a brief summary description of the ORIGEN2.1 and BOXER codes was given.

In the standard JNFL reference input (as described in Tables A.1 and A.2 in Appendix A) the key parameters have the values: burnup = 45 GWd$(t_{IHM})^{-1}$, enrichment = 4.5%, and power = 38 MW$(t_{IHM})^{-1}$. ORIGEN2.1 and BOXER calculations were run for this reference case and for the following 9 variations:

- The burnup was changed to 28, 33, and 55 GWd$(t_{IHM})^{-1}$.
- The enrichment was reduced to 3.0%, 3.5%, and 4.0%.
- The power was modified to 23.64, 27.87, and 46.44 MW$(t_{IHM})^{-1}$.

Note that only one of the key parameters was modified in these variations, while all others remained unchanged. The 9 variations and the values of the key parameters are summarised in Table E.1. The nuclide densities corresponding to the enrichments 3.0%, 3.5%, and 4.0% are shown in Tables E.2, E.3, and E.4, respectively. In all 9 variations it was assumed that the burnup was achieved within just one irradiation cycle, and the input of the codes was set up accordingly. Appropriate cross section libraries available within the ORIGEN2.1 code were chosen for to the key parameters for the cases and these are also specified in Appendix E.

3.3 Results

The results obtained from the ORIGEN2.1 and BOXER codes are listed in the tables of Appendix F. First, in Table F.1, the activities of the radionuclides in the fuel are given as calculated within ORIGEN2.1 for the reference cases JNFL in the 2nd column, and for the 9 variants in columns 3, 4, 6, 7, 8, 9, 11, 12, and 14, all at time of discharge. Table F.2 shows the same results calculated with BOXER. As before, the list of radionuclides is based on the list of safety relevant nuclides given in Appendix 5 of (Nagra 2002).

In order to allow for an easy comparison of the systematic trends of both code predictions for the activities as a function of the key parameters, the results of the 9 variations have been divided by the activities obtained for reference case 1, Table 2 (JNFL). The corresponding ratios are shown for the in columns 3, 4, 6, 7, 8, 9, 11, 12, and 14 of Tables F.3 and F.4 for the ORIGEN2.1 and BOXER codes, respectively. In both tables, the entries in columns 3-6 stand for the variations in burnup, in columns 7-10 for the variations in enrichment, and in columns 11-14 for the variations in power. Note, that, including reference case 1 (with burnup = 45 GWd$(t_{IHM})^{-1}$, enrichment = 4.5%, power = 38 MW$(t_{IHM})^{-1}$), each of the three series of increasing key parameters consists of 4 elements. In the following, all relative changes of the concentrations for a variation of the key parameters will be discussed in percent of the activity obtained for reference case 1, which is given in the 2nd column of Tables F.3 and F.4.

For the three series of increasing key parameters, the activities of all radionuclides, except four, show a clear trend, i.e., they are monotonically increasing or decreasing with increasing key parameters, or they roughly stay constant. For the purpose of classifying the trends, the ratios in Tables F.3 and F.4 have been coloured following the scheme:

- the four exceptions that do not show a clear trend have been highlighted in magenta,
- if the activities changed by less than 5%, they are considered to have approximately stayed constant, and the ratios are given in black,
- if an increase greater or equal than 5 percent occurred, the entry is printed in red,
- if there was a decrease greater or equal than 5 percent, the entry is given in blue.

Of course, to set the upper bound for increasing/decreasing to a minimum of ±5% is somewhat arbitrary, but a reasonable cut had to be made.

3.4 Discussion

3.4.1 Variation of burnup

Here, BOXER and ORIGEN2.1 calculations predict the same trend for all nuclides, except for the four radionuclides that do not show a clear trend (and are highlighted in magenta): ^{152}Eu in Table F.3 and ^{147}Pm, ^{233}U, ^{239}Pu in Table F.4. In detail it was found that:

- While the concentrations of ^{147}Pm resulting from an ORIGEN2.1 calculation slightly drop by 11% going from burnup 28GWd$(t_{IHM})^{-1}$ up to 55 GWd$(t_{IHM})^{-1}$, BOXER predicts first a small increase of 7% up to 45 GWd$(t_{IHM})^{-1}$ and then a decrease of 2%. This difference between the codes does not pose a severe problem because, by comparing the absolute activities for ^{147}Pm in column 2 of Tables F.3 and F.4, good agreement can be found, within roughly 20%. Due to the small dependence of the ^{147}Pm activity on burnup, this agreement deteriorates to roughly 30% over a range of burnups.
- For the activity of ^{152}Eu, BOXER predicts a monotonic increase of 20% over the range of burnup, but ORIGEN2.1 first gives an increase of 35% up to 45 GWd$(t_{IHM})^{-1}$ and then a decrease of 2%. As the ^{152}Eu concentration seems to be slightly overestimated by ORIGEN2.1 (see Table D.1) this difference in the trends does not pose a severe problem, i.e., ORIGEN2.1 predictions for the activity of ^{152}Eu should be reliable over a range of burnups.
- The concentrations of ^{233}U from an ORIGEN2.1 calculation rise by 26% over the range of burnups, while BOXER gives an increase of just 14% up to 45 GWd$(t_{IHM})^{-1}$, followed by a decrease of 1%. From the ^{233}U activities listed in Table D.1 for a burnup of 45 GWd$(t_{IHM})^{-1}$, it can be deduced, that ORIGEN2.1 calculations tend to underestimate the concentration of ^{233}U by more than 30%. Combined with the stronger increase found for ORIGEN2.1, it can be concluded that, especially for a low burnup, the ^{233}U activity predicted by ORIGEN2.1 will be too low by a factor of up to 2.
- For ^{239}Pu, ORIGEN2.1 predicts a monotonic rise of 7% compared to BOXER, which gives an increase of 6% up to a burnup of 45 GWd$(t_{IHM})^{-1}$, followed by a decrease of 1% for 55 GWd$(t_{IHM})^{-1}$. These differences are small and demonstrate that the good agreement found between the codes for 45 GWd$(t_{IHM})^{-1}$ (see Table D.1) should be valid for a wider range of burnups.

3.4.2 Variation of the enrichment

BOXER and ORIGEN2.1 results show a different trend for the following 10 nuclides: ^{10}Be, ^{151}Sm, ^{210}Pb, ^{228}Th, ^{229}Th, ^{232}U, ^{239}Pu, ^{241}Pu, ^{241}Am, and ^{242}Am^{m}. In detail:

- While BOXER predicts just a small decrease of 3% for ^{10}Be, ORIGEN2.1 gives a decrease of 17%. Taking into account the severe discrepancies found for the ^{10}Be activities obtained from 4 codes (see Table D.1) for an enrichment of 4.5%, it can be concluded that these discrepancies will extend over the whole range of enrichments.
- As the situation for the radionuclides ^{151}Sm, ^{228}Th, and ^{232}U happens to be very similar, they are discussed together. Their activity, as determined by ORIGEN2.1, essentially stays constant over the range of enrichments considered in contrast to the corresponding BOXER results that predict an increase in the range 17-18%. Following Table D.1, the activity of these nuclides is slightly overestimated by ORIGEN2.1 at an enrichment of 4.5%. Hence the deviation between BOXER and ORIGEN2.1 should become even smaller for lower enrichments.
- In contrast to ORIGEN2.1 that predicts the activity of ^{210}Pb to drop by 11%, BOXER gives an increase for the ^{210}Pb concentration of 25% over the range of enrichments. As in the case of ^{10}Be: Taking into account the severe discrepancies found for the ^{210}Pb activities obtained from the 4 codes (see Table D.1) for an enrichment of 4.5%, it can be concluded that these discrepancies will pose a problem over the whole range of enrichments.
- While the activities of ^{229}Th predicted by BOXER essentially stay constant, ORIGEN2.1 results show a decrease of 8%. Taking into account that ORIGEN2.1 seems to overestimate

the ^{229}Th activity by a factor of 2 (see Table D.1) for an enrichment of 4.5%, it can be concluded that this deviation will extend over the whole range of enrichments.

- The activity of ^{239}Pu, as determined by ORIGEN2.1, essentially stays constant over the range of enrichments considered, in contrast to the corresponding BOXER results that predict an increase of 13%. Following Table D.1, the activity of ^{239}Pu is slightly underestimated by ORIGEN2.1 at an enrichment of 4.5%. Hence the deviation between BOXER and ORIGEN2.1 should become even smaller for lower enrichments.
- While the activities of ^{241}Pu predicted by BOXER essentially stay constant, ORIGEN2.1 results show a decrease of 19%. Taking into account that ORIGEN2.1 seems to underestimate the ^{241}Pu activity by roughly 10% (see Table D.1) for an enrichment of 4.5%, it can be concluded that the deviation will turn into a small overestimate for lower enrichments.
- While BOXER predicts an increase of 14% and 19% for the radionuclides ^{241}Am, and ^{242}Am^{m}, respectively, ORIGEN2.1 gives a decrease of 11% and 16%. Following Table A.1, the activity of ^{241}Am and ^{242}Am^{m} is slightly underestimated by ORIGEN2.1 at an enrichment of 4.5%. Hence for ^{241}Am, the deviation will diminish for lower enrichments, and for ^{242}Am^{m} it will turn into an overestimate.

3.4.3 Variation of the power level

Comparing the colour pattern of the last four columns in Tables F.3 and F.4, at first sight trends seem to be different for 7 entries: ^{3}H, ^{94}Nb, ^{151}Sm, ^{244}Cm, ^{245}Cm, ^{246}Cm, and the total activity from α-decays. However, studying the ratios in detail for ^{3}H, ^{151}Sm, ^{244}Cm, ^{245}Cm, and ^{246}Cm, it is clear that they do have the same trend: they all increase slightly within a range of 1 to 7%. The change in colour is due to the somewhat arbitrary cut that was set at ±5% for increasing/decreasing. The same holds for the total activity from α-decays. Both ORIGEN2.1 and BOXER predict a decrease by 5% and 4%, respectively. There is only one radionuclide, ^{94}Nb, for which ORIGEN2.1 and BOXER produce significantly different trends. While ORIGEN2.1 gives a constant activity of ^{94}Nb for all power levels, the BOXER results suggest an increase in activity by roughly 40% over the considered power range. According to Table D.1, ORIGEN2.1 underestimates the activity of ^{94}Nb by a factor of roughly 2 for a power level of 38 MW$(t_{IHM})^{-1}$. Thus, for higher power levels, this deviation will become worse, for lower power levels it will improve slightly.

3.5 Summary

By comparing the results of BOXER and ORIGEN2.1 for a range of burnups, enrichments and power levels it was found that:

- For most of the radionuclides, BOXER and ORIGEN2.1 calculations give similar trends for a variation of the key parameters.
- The deviations between the predictions of the codes that show up for a small number of nuclides tend to *moderately* increase with burnup and enrichment.

Hence the magnitude of the differences found for reference case 1, Table 2, (JNFL, which showed the highest enrichment and the second highest burnup in the ranges of key parameters taken into account) should give a fair, representative and conservative estimate of the error that must be assigned to concentrations predicted by ORIGEN2.1 calculations.

Generally it was found that ORIGEN2.1 can reliably predict the activities of most of the safety relevant nuclides over a wide range of key parameters.

4 Conclusions

The cross code comparison performed in chapter 2 has shown that the activities predicted by ORIGEN2.1 calculations are consistent with the predictions of three other codes for most of the safety relevant nuclides. Only for 9 radionuclides (out of the list of 64 safety relevant nuclides) considerable differences in the results of the codes were found.

The sensitivity study performed in chapter 3 pointed out that *the agreements and the deviations* noted in chapter 2 do not change significantly for a variation of the key parameters burnup, enrichment and power level.

Therefore the method suggested in chapter 2 to correct some of the deficiencies in the predicted concentrations of ORIGEN2.1 by multiplying with a phenomenological factor (between roughly 2 and 4 for the radionuclides ^{14}C, ^{93}Mo, and ^{210}Po), may be applied to provide a conservative upper bound for the activity.

Activities for safety relevant radionuclides that are calculated within ORIGEN2.1 should be used with care. An appropriate error bar should be assigned to all of the obtained values within ORIGEN2.1 calculations. Fair estimates of such appropriate error bars can be extracted from the results obtained for reference case 1, Table 2 (JNFL), i.e. from the ratios listed in the last 3 columns of Table C.1.

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Appendix A

Table A.1: Basic input data for the UO_2 pin cell used in all four reference cases. (BOL= beginning of life, EOL = end of life)

Parameter	**Value**
Fuel diameter [cm]	0.913
Clad inner diameter [cm]	0.930
Clad outer diameter [cm]	1.09152
Cell pitch [cm]	1.50582
Fuel density [g cm^{-3}]	10.35
Clad density [g cm^{-3}]	6.55
Coolant pressure [bar]	158.8
Boron concentration BOL [ppm]	500
Boron concentration EOL [ppm]	500
Fuel temperature [°C]	600
Clad temperature [°C]	315
Coolant temperature [°C]	300

Within the ORIGEN-ARP calculations the fuel type option "17x17 PWR" was chosen for all reference cases. Also, in all reference cases, for neutrons and photons, respectively, the libraries "238GrpENDF5" and "44GrpENDF5" corresponding to 238 and 44 energy groups and based on the ENDF/B-V cross section library were used.

Table A.2: Basic input data and nuclide densities for reference case 1 (JNFL),

Parameter	**Value**
Thermal power [MW $(t_{IHM})^{-1}$]	38.0
Burnup [GWd $(t_{IHM})^{-1}$]	45.0
Enrichment [%]	4.5

Nuclide	**Density [g $(t_{IHM})^{-1}$]**
^{232}U	1.0E-04
^{234}U	450
^{235}U	45000
^{236}U	250
^{238}U	954300
^{16}O	134000

Within the ORIGEN2.1 calculation the RWR-UE cross section library was chosen corresponding to an ORIGEN2 reactor model designed to use UO_2 fuel with an enrichment of 4.2 % to achieve an extended burnup of 50 GWd(t_{IHM})$^{-1}$ (library maximum).

Table A.3: Basic input data and nuclide densities for reference case 2 (BNFL),

Parameter	**Value**
Thermal power [MW (t_{IHM})$^{-1}$]	27.1
Burnup [GWd (t_{IHM})$^{-1}$]	33.0
Enrichment [%]	3.35

Nuclide	**Density [g (t_{IHM})$^{-1}$]**
^{232}U	1.0E-04
^{234}U	335
^{235}U	33500
^{236}U	250
^{238}U	965915
^{16}O	134000

Within the ORIGEN2.1 calculation the RWR-US cross section library was chosen corresponding to an ORIGEN2 reactor model designed to use UO_2 fuel with an enrichment of 3.2 % to achieve a standard burnup of 33 GWd(t_{IHM})$^{-1}$ (library maximum).

Table A.4: Basic input data and nuclide densities for reference case 3 (COGEMA), Table 2.

Parameter	**Value**
Thermal power [MW (t_{IHM})$^{-1}$]	30.0
Burnup [GWd (t_{IHM})$^{-1}$]	33.0
Enrichment [%]	3.5

Nuclide	**Density [g (t_{IHM})$^{-1}$]**
^{232}U	1.0E-04
^{234}U	350
^{235}U	35000
^{236}U	250
^{238}U	964400
^{16}O	134000

Within the ORIGEN2.1 calculation the RWR-US cross section library was chosen corresponding to an ORIGEN2 reactor model designed to use UO_2 fuel with an enrichment of 3.2 % to achieve a standard burnup of 33 GWd(t_{IHM})$^{-1}$ (library maximum).

Table A.5: Basic input data and nuclide densities for reference case 4 (TVF), Table 2.

Parameter	**Value**
Thermal power [MW $(t_{IHM})^{-1}$]	35.0
Burnup [GWd $(t_{IHM})^{-1}$]	28.0
Enrichment [%]	4.0

Nuclide	**Density [g $(t_{IHM})^{-1}$]**
^{232}U	1.0E-04
^{234}U	400
^{235}U	40000
^{236}U	250
^{238}U	959350
^{16}O	134000

Within the ORIGEN2.1 calculation the RWR-US cross section library was chosen corresponding to an ORIGEN2 reactor model designed to use UO_2 fuel with an enrichment of 3.2 % to achieve a standard burnup of 33 GWd$(t_{IHM})^{-1}$ (library maximum).

Appendix B

Table B.1: Nuclide activities ($Bq(t_{IHM})^{-1}$) calculated with ORIGEN2.1 for reference case 1 (JNFL) from Table 2, at various decay times (DISQ = at time of discharge).

Nuclide	DISQ	1.0a	3.0a	10.0a	100.0a	1.0E03a	1.0E04a	1.0E05a	1.0E06a
H3	3.59E+13	3.39E+13	3.03E+13	2.04E+13	1.29E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Be10	2.03E+05	2.03E+05	2.03E+05	2.03E+05	2.03E+05	2.03E+05	2.02E+05	1.94E+05	1.32E+05
C14	1.92E+10	1.92E+10	1.92E+10	1.92E+10	1.90E+10	1.70E+10	5.73E+09	1.07E+05	0.00E+00
Cl36	3.83E+08	3.83E+08	3.83E+08	3.83E+08	3.83E+08	3.82E+08	3.74E+08	3.04E+08	3.80E+07
Ca41	4.74E+06	4.74E+06	4.74E+06	4.74E+06	4.73E+06	4.71E+06	4.43E+06	2.42E+06	5.66E+03
Fe55	3.20E+11	2.49E+11	1.50E+11	2.53E+10	3.01E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co60	5.78E+12	5.07E+12	3.90E+12	1.55E+12	1.13E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni59	3.53E+08	3.53E+08	3.53E+08	3.53E+08	3.52E+08	3.49E+08	3.22E+08	1.40E+08	3.42E+04
Ni63	5.04E+10	5.00E+10	4.94E+10	4.70E+10	2.54E+10	5.27E+07	0.00E+00	0.00E+00	0.00E+00
Se79	1.22E+09	1.22E+09	1.22E+09	1.22E+09	1.22E+09	1.22E+09	1.21E+09	1.15E+09	6.49E+08
Kr85	4.81E+14	4.51E+14	3.96E+14	2.52E+14	7.67E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rb87	1.10E+06	1.10E+06	1.10E+06	1.10E+06	1.10E+06	1.10E+06	1.10E+06	1.10E+06	1.10E+06
Sr90	3.88E+15	3.79E+15	3.61E+15	3.05E+15	3.45E+14	1.20E+05	0.00E+00	0.00E+00	0.00E+00
Zr93	9.52E+10	9.52E+10	9.52E+10	9.52E+10	9.52E+10	9.52E+10	9.48E+10	9.09E+10	6.00E+10
Nb93M	6.47E+09	1.00E+10	1.66E+10	3.58E+10	8.93E+10	9.04E+10	9.00E+10	8.64E+10	5.70E+10
Nb94	6.39E+06	6.39E+06	6.39E+06	6.39E+06	6.37E+06	6.17E+06	4.52E+06	2.00E+05	5.68E-09
Mo93	2.13E+07	2.13E+07	2.13E+07	2.13E+07	2.09E+07	1.79E+07	3.76E+06	6.35E-01	0.00E+00
Tc99	6.63E+11	6.66E+11	6.66E+11	6.66E+11	6.66E+11	6.64E+11	6.45E+11	4.79E+11	2.46E+10
Ru106	2.29E+16	1.16E+16	3.00E+15	2.62E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pd107	5.04E+09	5.04E+09	5.04E+09	5.04E+09	5.04E+09	5.04E+09	5.04E+09	4.99E+09	4.53E+09
Ag108M	1.37E+08	1.37E+08	1.36E+08	1.35E+08	1.16E+08	2.61E+07	8.61E+00	0.00E+00	0.00E+00
Cd113M	2.52E+12	2.41E+12	2.19E+12	1.57E+12	2.19E+10	6.08E-09	0.00E+00	0.00E+00	0.00E+00
Sn121M	8.77E+09	8.66E+09	8.44E+09	7.73E+09	2.49E+09	2.95E+04	0.00E+00	0.00E+00	0.00E+00

Table B.1: (cont.)

Nuclide	DISQ	1.0a	3.0a	10.0a	100.0a	1.0E03a	1.0E04a	1.0E05a	1.0E06a
Sn126	1.53E+10	1.53E+10	1.53E+10	1.53E+10	1.53E+10	1.53E+10	1.49E+10	1.14E+10	7.97E+08
Sb125	6.23E+14	4.89E+14	2.96E+14	5.14E+13	8.52E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I129	1.52E+09	1.53E+09	1.53E+09	1.53E+09	1.53E+09	1.53E+09	1.53E+09	1.52E+09	1.46E+09
Cs134	8.68E+15	6.20E+15	3.16E+15	3.00E+14	2.12E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs135	2.50E+10	2.51E+10	2.51E+10	2.51E+10	2.51E+10	2.51E+10	2.50E+10	2.43E+10	1.85E+10
Cs137	5.18E+15	5.06E+15	4.84E+15	4.11E+15	5.21E+14	5.45E+05	0.00E+00	0.00E+00	0.00E+00
Pm147	5.67E+15	4.58E+15	2.70E+15	4.23E+14	1.93E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm147	7.44E+04	1.09E+05	1.55E+05	2.11E+05	2.22E+05	2.22E+05	2.22E+05	2.22E+05	2.22E+05
Sm151	2.00E+13	2.01E+13	1.98E+13	1.88E+13	9.63E+12	1.18E+10	0.00E+00	0.00E+00	0.00E+00
Eu152	4.11E+11	3.90E+11	3.51E+11	2.44E+11	2.27E+09	1.07E-11	0.00E+00	0.00E+00	0.00E+00
Eu154	4.71E+14	4.35E+14	3.72E+14	2.14E+14	1.79E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Eu155	3.36E+14	2.91E+14	2.17E+14	7.84E+13	1.60E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ho166M	1.02E+08	1.02E+08	1.02E+08	1.01E+08	9.60E+07	5.71E+07	3.15E+05	0.00E+00	0.00E+00
Pb210	1.92E+02	2.53E+02	4.43E+02	2.71E+03	8.17E+05	1.89E+08	7.83E+09	6.07E+10	2.09E+10
Po210	1.35E+09	2.25E+08	5.80E+06	2.73E+03	8.17E+05	1.89E+08	7.83E+09	6.07E+10	2.09E+10
Ra226	1.42E+03	2.27E+03	4.68E+03	2.09E+04	1.49E+06	1.89E+08	7.83E+09	6.07E+10	2.10E+10
Ra228	1.84E-01	3.63E-01	8.97E-01	4.02E+00	7.25E+01	7.26E+02	8.24E+03	9.88E+04	9.91E+05
Ac227	3.19E+04	6.26E+04	1.23E+05	3.20E+05	2.03E+06	1.62E+07	1.49E+08	9.18E+08	1.13E+09
Th228	1.61E+08	3.58E+08	7.69E+08	1.57E+09	7.60E+08	1.19E+05	3.65E+04	1.18E+05	9.91E+05
Th229	1.08E+04	1.08E+04	1.10E+04	1.18E+04	5.50E+04	5.90E+06	7.38E+08	1.90E+10	4.20E+10
Th230	1.69E+06	2.24E+06	3.35E+06	7.38E+06	7.25E+07	1.03E+09	1.01E+10	6.06E+10	2.10E+10
Th232	1.41E+00	2.12E+00	3.53E+00	8.50E+00	7.25E+01	7.26E+02	8.24E+03	9.88E+04	9.91E+05
Pa231	1.00E+06	1.02E+06	1.05E+06	1.16E+06	2.53E+06	1.62E+07	1.49E+08	9.18E+08	1.13E+09

Table B.1: (cont.)

Nuclide	DISQ	1.0a	3.0a	10.0a	100.0a	1.0E03a	1.0E04a	1.0E05a	1.0E06a
U232	6.57E+08	9.32E+08	1.30E+09	1.71E+09	7.39E+08	1.16E+05	2.82E+04	1.88E+04	3.28E+02
U233	7.74E+05	8.62E+05	1.03E+06	1.60E+06	9.64E+06	1.57E+08	2.25E+09	1.89E+10	4.19E+10
U234	5.97E+10	6.01E+10	6.10E+10	6.40E+10	9.05E+10	1.16E+11	1.13E+11	9.05E+10	1.78E+10
U235	7.21E+08	7.21E+08	7.21E+08	7.21E+08	7.22E+08	7.32E+08	8.20E+08	1.10E+09	1.13E+09
U236	1.44E+10	1.44E+10	1.44E+10	1.44E+10	1.45E+10	1.50E+10	1.83E+10	2.04E+10	1.98E+10
U238	1.15E+10	1.15E+10	1.15E+10	1.15E+10	1.15E+10	1.15E+10	1.15E+10	1.15E+10	1.16E+10
Np237	1.81E+10	1.85E+10	1.85E+10	1.86E+10	2.28E+10	4.70E+10	5.44E+10	5.29E+10	3.95E+10
Pu238	1.46E+14	1.54E+14	1.54E+14	1.46E+14	7.17E+13	6.10E+10	3.92E-10	0.00E+00	0.00E+00
Pu239	1.14E+13	1.16E+13	1.16E+13	1.16E+13	1.15E+13	1.13E+13	8.81E+12	6.74E+11	5.88E+03
Pu240	2.12E+13	2.12E+13	2.13E+13	2.13E+13	2.13E+13	1.94E+13	7.49E+12	5.58E+08	2.17E+04
Pu241	5.25E+15	5.00E+15	4.54E+15	3.24E+15	4.20E+13	1.02E+10	4.88E+09	3.17E+06	0.00E+00
Pu242	8.20E+10	8.20E+10	8.20E+10	8.20E+10	8.20E+10	8.19E+10	8.06E+10	6.82E+10	1.29E+10
Am241	4.61E+12	1.28E+13	2.81E+13	7.07E+13	1.56E+14	3.72E+13	4.90E+09	3.34E+06	0.00E+00
Am242M	3.99E+11	3.97E+11	3.93E+11	3.80E+11	2.44E+11	2.92E+09	1.78E-10	0.00E+00	0.00E+00
Am243	8.85E+11	8.86E+11	8.86E+11	8.85E+11	8.78E+11	8.07E+11	3.46E+11	7.29E+07	5.88E+03
Cm244	1.15E+14	1.11E+14	1.03E+14	7.84E+13	2.50E+12	2.69E-03	0.00E+00	0.00E+00	0.00E+00
Cm245	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.09E+10	1.02E+10	4.88E+09	3.17E+06	0.00E+00
Cm246	1.99E+09	1.99E+09	1.99E+09	1.99E+09	1.96E+09	1.72E+09	4.60E+08	8.61E+02	0.00E+00
Total	5.39E+16	3.83E+16	2.35E+16	1.21E+16	1.18E+15	6.99E+13	1.79E+13	1.90E+12	4.40E+11
Alpha	3.00E+14	3.12E+14	3.19E+14	3.29E+14	2.64E+14	6.90E+13	1.70E+13	1.14E+12	2.51E+11
Beta/Gamma	5.36E+16	3.80E+16	2.32E+16	1.18E+16	9.20E+14	9.40E+11	8.96E+11	7.61E+11	1.90E+11

Table B.2: Nuclide activities ($Bq(t_{IHM})^{-1}$) calculated with ORIGEN2.1 for reference case 2 (BNFL) from Table2, at various decay times (DISQ = at time of discharge).

Nuclide	DISQ	1.0a	3.0a	10.0a	100.0a	1.0E03a	1.0E04a	1.0E05a	1.0E06a
H3	2.94E+13	2.78E+13	2.48E+13	1.68E+13	1.06E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Be10	1.47E+05	1.47E+05	1.47E+05	1.47E+05	1.47E+05	1.47E+05	1.46E+05	1.40E+05	9.51E+04
C14	2.02E+10	2.02E+10	2.02E+10	2.02E+10	2.00E+10	1.79E+10	6.03E+09	1.13E+05	0.00E+00
Cl36	4.11E+08	4.11E+08	4.11E+08	4.11E+08	4.11E+08	4.10E+08	4.02E+08	3.26E+08	4.08E+07
Ca41	5.09E+06	5.09E+06	5.09E+06	5.09E+06	5.09E+06	5.06E+06	4.76E+06	2.60E+06	6.08E+03
Fe55	3.24E+11	2.52E+11	1.51E+11	2.56E+10	3.05E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co60	5.59E+12	4.91E+12	3.77E+12	1.50E+12	1.09E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni59	3.75E+08	3.75E+08	3.75E+08	3.75E+08	3.74E+08	3.72E+08	3.42E+08	1.49E+08	3.63E+04
Ni63	5.38E+10	5.35E+10	5.27E+10	5.03E+10	2.71E+10	5.63E+07	0.00E+00	0.00E+00	0.00E+00
Se79	8.94E+08	8.94E+08	8.94E+08	8.94E+08	8.94E+08	8.93E+08	8.88E+08	8.39E+08	4.76E+08
Kr85	3.43E+14	3.21E+14	2.82E+14	1.80E+14	5.46E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rb87	7.84E+05	7.84E+05	7.84E+05	7.84E+05	7.84E+05	7.84E+05	7.84E+05	7.84E+05	7.84E+05
Sr90	2.76E+15	2.70E+15	2.57E+15	2.17E+15	2.46E+14	8.52E+04	0.00E+00	0.00E+00	0.00E+00
Zr93	6.88E+10	6.88E+10	6.88E+10	6.88E+10	6.88E+10	6.88E+10	6.85E+10	6.57E+10	4.34E+10
Nb93M	4.80E+09	7.34E+09	1.21E+10	2.60E+10	6.46E+10	6.54E+10	6.51E+10	6.24E+10	4.12E+10
Nb94	5.17E+06	5.17E+06	5.17E+06	5.17E+06	5.15E+06	4.99E+06	3.66E+06	1.62E+05	4.59E-09
Mo93	1.92E+07	1.92E+07	1.92E+07	1.92E+07	1.89E+07	1.62E+07	3.40E+06	5.72E-01	0.00E+00
Tc99	4.95E+11	4.97E+11	4.97E+11	4.97E+11	4.97E+11	4.95E+11	4.81E+11	3.57E+11	1.83E+10
Ru106	1.73E+16	8.80E+15	2.27E+15	1.98E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pd107	3.99E+09	3.99E+09	3.99E+09	3.99E+09	3.99E+09	3.99E+09	3.99E+09	3.95E+09	3.59E+09
Ag108M	1.35E+08	1.35E+08	1.34E+08	1.33E+08	1.15E+08	2.57E+07	8.49E+00	0.00E+00	0.00E+00
Cd113M	1.90E+12	1.81E+12	1.65E+12	1.18E+12	1.65E+10	4.57E-09	0.00E+00	0.00E+00	0.00E+00
Sn121M	6.82E+09	6.73E+09	6.56E+09	6.01E+09	1.93E+09	2.29E+04	0.00E+00	0.00E+00	0.00E+00

Table B.2: (cont.)

Nuclide	DISQ	1.0a	3.0a	10.0a	100.0a	1.0E03a	1.0E04a	1.0E05a	1.0E06a
Sn126	1.19E+10	1.19E+10	1.19E+10	1.18E+10	1.18E+10	1.18E+10	1.15E+10	8.81E+09	6.16E+08
Sb125	4.81E+14	3.77E+14	2.29E+14	3.97E+13	6.57E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I129	1.15E+09	1.16E+09	1.16E+09	1.16E+09	1.16E+09	1.16E+09	1.16E+09	1.15E+09	1.11E+09
Cs134	5.39E+15	3.85E+15	1.96E+15	1.86E+14	1.31E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs135	1.70E+10	1.71E+10	1.71E+10	1.71E+10	1.71E+10	1.70E+10	1.70E+10	1.65E+10	1.26E+10
Cs137	3.80E+15	3.71E+15	3.54E+15	3.02E+15	3.82E+14	4.00E+05	0.00E+00	0.00E+00	0.00E+00
Pm147	4.65E+15	3.73E+15	2.20E+15	3.45E+14	1.57E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm147	6.17E+04	8.96E+04	1.28E+05	1.73E+05	1.82E+05	1.82E+05	1.82E+05	1.82E+05	1.82E+05
Sm151	1.34E+13	1.35E+13	1.33E+13	1.26E+13	6.44E+12	7.85E+09	0.00E+00	0.00E+00	0.00E+00
Eu152	2.99E+11	2.84E+11	2.56E+11	1.78E+11	1.65E+09	7.80E-12	0.00E+00	0.00E+00	0.00E+00
Eu154	3.14E+14	2.90E+14	2.48E+14	1.43E+14	1.19E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Eu155	2.15E+14	1.86E+14	1.39E+14	5.00E+13	1.02E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ho166M	7.21E+07	7.21E+07	7.20E+07	7.17E+07	6.81E+07	4.05E+07	2.24E+05	0.00E+00	0.00E+00
Pb210	1.24E+02	1.72E+02	3.31E+02	2.20E+03	6.41E+05	1.36E+08	5.59E+09	4.36E+10	1.83E+10
Po210	1.13E+09	1.89E+08	4.88E+06	2.22E+03	6.41E+05	1.36E+08	5.59E+09	4.36E+10	1.83E+10
Ra226	1.17E+03	1.88E+03	3.88E+03	1.71E+04	1.16E+06	1.36E+08	5.60E+09	4.37E+10	1.83E+10
Ra228	1.41E-01	2.73E-01	6.61E-01	2.91E+00	5.22E+01	5.25E+02	6.12E+03	7.60E+04	7.64E+05
Ac227	2.35E+04	4.57E+04	8.94E+04	2.36E+05	1.72E+06	1.53E+07	1.43E+08	8.89E+08	1.09E+09
Th228	1.19E+08	2.37E+08	4.68E+08	8.97E+08	4.28E+08	6.53E+04	2.03E+04	8.54E+04	7.64E+05
Th229	7.78E+03	7.82E+03	7.93E+03	8.46E+03	3.71E+04	4.36E+06	5.83E+08	1.51E+10	3.33E+10
Th230	1.41E+06	1.86E+06	2.76E+06	5.98E+06	5.57E+07	7.38E+08	7.18E+09	4.36E+10	1.83E+10
Th232	1.04E+00	1.55E+00	2.57E+00	6.15E+00	5.22E+01	5.25E+02	6.12E+03	7.60E+04	7.64E+05
Pa231	7.22E+05	7.39E+05	7.69E+05	8.71E+05	2.19E+06	1.53E+07	1.43E+08	8.89E+08	1.09E+09

Table B.2: (cont.)

Nuclide	DISQ	1.0a	3.0a	10.0a	100.0a	1.0E03a	1.0E04a	1.0E05a	1.0E06a
U232	4.26E+08	5.69E+08	7.61E+08	9.66E+08	4.16E+08	6.34E+04	1.42E+04	9.47E+03	1.65E+02
U233	5.01E+05	5.59E+05	6.70E+05	1.04E+06	6.47E+06	1.19E+08	1.78E+09	1.50E+10	3.33E+10
U234	4.84E+10	4.87E+10	4.92E+10	5.10E+10	6.72E+10	8.28E+10	8.10E+10	6.55E+10	1.60E+10
U235	6.91E+08	6.91E+08	6.91E+08	6.91E+08	6.92E+08	7.02E+08	7.90E+08	1.07E+09	1.09E+09
U236	1.03E+10	1.03E+10	1.03E+10	1.04E+10	1.04E+10	1.09E+10	1.39E+10	1.57E+10	1.53E+10
U238	1.17E+10	1.17E+10	1.17E+10	1.17E+10	1.17E+10	1.17E+10	1.17E+10	1.17E+10	1.17E+10
Np237	1.18E+10	1.21E+10	1.21E+10	1.22E+10	1.58E+10	3.68E+10	4.32E+10	4.20E+10	3.14E+10
Pu238	8.75E+13	9.39E+13	9.41E+13	8.91E+13	4.39E+13	3.79E+10	3.34E-10	0.00E+00	0.00E+00
Pu239	1.13E+13	1.15E+13	1.15E+13	1.15E+13	1.15E+13	1.12E+13	8.72E+12	6.63E+11	2.35E+03
Pu240	1.91E+13	1.92E+13	1.92E+13	1.92E+13	1.91E+13	1.74E+13	6.72E+12	5.00E+08	1.19E+04
Pu241	4.53E+15	4.31E+15	3.92E+15	2.79E+15	3.62E+13	4.54E+09	2.18E+09	1.42E+06	0.00E+00
Pu242	6.22E+10	6.22E+10	6.22E+10	6.22E+10	6.22E+10	6.21E+10	6.11E+10	5.17E+10	9.80E+09
Am241	4.91E+12	1.20E+13	2.51E+13	6.19E+13	1.35E+14	3.23E+13	2.20E+09	1.49E+06	0.00E+00
Am242M	3.40E+11	3.38E+11	3.35E+11	3.23E+11	2.08E+11	2.49E+09	1.52E-10	0.00E+00	0.00E+00
Am243	5.84E+11	5.84E+11	5.84E+11	5.84E+11	5.79E+11	5.32E+11	2.28E+11	4.81E+07	2.34E+03
Cm244	6.39E+13	6.15E+13	5.69E+13	4.36E+13	1.39E+12	1.49E-03	0.00E+00	0.00E+00	0.00E+00
Cm245	4.92E+09	4.92E+09	4.92E+09	4.91E+09	4.88E+09	4.53E+09	2.18E+09	1.41E+06	0.00E+00
Cm246	9.49E+08	9.49E+08	9.48E+08	9.47E+08	9.35E+08	8.20E+08	2.19E+08	4.10E+02	0.00E+00
Total	4.00E+16	2.85E+16	1.76E+16	9.20E+15	8.83E+14	6.23E+13	1.66E+13	1.58E+12	3.48E+11
Alpha	1.88E+14	1.99E+14	2.08E+14	2.26E+14	2.12E+14	6.16E+13	1.59E+13	1.01E+12	2.08E+11
Beta/Gamma	3.98E+16	2.83E+16	1.74E+16	8.97E+15	6.71E+14	6.98E+11	6.63E+11	5.61E+11	1.41E+11

Table B.3: Nuclide activities ($Bq(t_{IHM})^{-1}$) calculated with ORIGEN2.1 for reference case 3 (COGEMA) from Table 2, at various decay times (DISQ = at time of discharge).

Nuclide	DISQ	1.0a	3.0a	10.0a	100.0a	1.0E03a	1.0E04a	1.0E05a	1.0E06a
H3	2.93E+13	2.77E+13	2.48E+13	1.67E+13	1.06E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Be10	1.45E+05	1.45E+05	1.45E+05	1.45E+05	1.45E+05	1.45E+05	1.44E+05	1.39E+05	9.38E+04
C14	1.96E+10	1.96E+10	1.96E+10	1.96E+10	1.94E+10	1.74E+10	5.84E+09	1.09E+05	0.00E+00
Cl36	3.99E+08	3.99E+08	3.99E+08	3.99E+08	3.99E+08	3.99E+08	3.90E+08	3.17E+08	3.96E+07
Ca41	4.94E+06	4.94E+06	4.94E+06	4.94E+06	4.93E+06	4.90E+06	4.61E+06	2.52E+06	5.89E+03
Fe55	3.26E+11	2.53E+11	1.52E+11	2.57E+10	3.06E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co60	5.55E+12	4.87E+12	3.74E+12	1.49E+12	1.08E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni59	3.65E+08	3.65E+08	3.65E+08	3.65E+08	3.65E+08	3.62E+08	3.33E+08	1.45E+08	3.54E+04
Ni63	5.23E+10	5.20E+10	5.13E+10	4.88E+10	2.63E+10	5.48E+07	0.00E+00	0.00E+00	0.00E+00
Se79	8.97E+08	8.97E+08	8.97E+08	8.97E+08	8.97E+08	8.96E+08	8.91E+08	8.42E+08	4.77E+08
Kr85	3.51E+14	3.29E+14	2.89E+14	1.84E+14	5.59E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rb87	7.95E+05	7.95E+05	7.95E+05	7.95E+05	7.95E+05	7.95E+05	7.95E+05	7.95E+05	7.95E+05
Sr90	2.82E+15	2.75E+15	2.62E+15	2.21E+15	2.50E+14	8.68E+04	0.00E+00	0.00E+00	0.00E+00
Zr93	6.95E+10	6.95E+10	6.95E+10	6.95E+10	6.95E+10	6.95E+10	6.92E+10	6.63E+10	4.38E+10
Nb93M	4.39E+09	6.98E+09	1.18E+10	2.59E+10	6.52E+10	6.60E+10	6.57E+10	6.30E+10	4.16E+10
Nb94	5.00E+06	5.00E+06	5.00E+06	5.00E+06	4.98E+06	4.83E+06	3.53E+06	1.56E+05	4.44E-09
Mo93	1.86E+07	1.86E+07	1.86E+07	1.86E+07	1.83E+07	1.57E+07	3.29E+06	5.55E-01	0.00E+00
Tc99	4.96E+11	4.98E+11	4.98E+11	4.98E+11	4.98E+11	4.97E+11	4.82E+11	3.58E+11	1.84E+10
Ru106	1.77E+16	9.01E+15	2.32E+15	2.03E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pd107	3.84E+09	3.84E+09	3.84E+09	3.84E+09	3.84E+09	3.84E+09	3.83E+09	3.80E+09	3.45E+09
Ag108M	1.31E+08	1.31E+08	1.31E+08	1.29E+08	1.11E+08	2.50E+07	8.25E+00	0.00E+00	0.00E+00
Cd113M	1.85E+12	1.76E+12	1.60E+12	1.15E+12	1.60E+10	4.44E-09	0.00E+00	0.00E+00	0.00E+00
Sn121M	6.68E+09	6.59E+09	6.43E+09	5.89E+09	1.89E+09	2.25E+04	0.00E+00	0.00E+00	0.00E+00

Table B.3: (cont.)

Nuclide	DISQ	1.0a	3.0a	10.0a	100.0a	1.0E03a	1.0E04a	1.0E05a	1.0E06a
Sn126	1.16E+10	1.16E+10	1.16E+10	1.16E+10	1.16E+10	1.16E+10	1.13E+10	8.65E+09	6.05E+08
Sb125	4.86E+14	3.81E+14	2.31E+14	4.01E+13	6.64E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I129	1.14E+09	1.15E+09	1.15E+09	1.15E+09	1.15E+09	1.15E+09	1.14E+09	1.14E+09	1.10E+09
Cs134	5.41E+15	3.87E+15	1.97E+15	1.87E+14	1.32E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs135	1.62E+10	1.62E+10	1.62E+10	1.62E+10	1.62E+10	1.62E+10	1.62E+10	1.58E+10	1.20E+10
Cs137	3.81E+15	3.72E+15	3.56E+15	3.03E+15	3.83E+14	4.01E+05	0.00E+00	0.00E+00	0.00E+00
Pm147	4.86E+15	3.91E+15	2.30E+15	3.61E+14	1.65E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm147	5.77E+04	8.70E+04	1.27E+05	1.75E+05	1.84E+05	1.84E+05	1.84E+05	1.84E+05	1.84E+05
Sm151	1.35E+13	1.36E+13	1.34E+13	1.27E+13	6.51E+12	7.94E+09	0.00E+00	0.00E+00	0.00E+00
Eu152	2.81E+11	2.67E+11	2.40E+11	1.67E+11	1.55E+09	7.34E-12	0.00E+00	0.00E+00	0.00E+00
Eu154	3.06E+14	2.82E+14	2.41E+14	1.39E+14	1.16E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Eu155	2.10E+14	1.81E+14	1.35E+14	4.88E+13	9.96E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ho166M	6.57E+07	6.57E+07	6.56E+07	6.54E+07	6.20E+07	3.69E+07	2.04E+05	0.00E+00	0.00E+00
Pb210	1.08E+02	1.51E+02	3.00E+02	2.16E+03	6.66E+05	1.38E+08	5.67E+09	4.42E+10	1.83E+10
Po210	1.21E+09	2.02E+08	5.21E+06	2.18E+03	6.66E+05	1.38E+08	5.67E+09	4.42E+10	1.83E+10
Ra226	1.01E+03	1.70E+03	3.69E+03	1.72E+04	1.20E+06	1.38E+08	5.67E+09	4.42E+10	1.84E+10
Ra228	1.18E-01	2.45E-01	6.29E-01	2.92E+00	5.38E+01	5.41E+02	6.27E+03	7.72E+04	7.76E+05
Ac227	2.01E+04	4.11E+04	8.27E+04	2.24E+05	1.77E+06	1.65E+07	1.54E+08	9.41E+08	1.15E+09
Th228	1.05E+08	2.17E+08	4.40E+08	8.61E+08	4.12E+08	6.33E+04	2.03E+04	8.65E+04	7.76E+05
Th229	6.85E+03	6.90E+03	7.01E+03	7.54E+03	3.62E+04	4.30E+06	5.71E+08	1.47E+10	3.26E+10
Th230	1.35E+06	1.83E+06	2.78E+06	6.18E+06	5.77E+07	7.49E+08	7.27E+09	4.41E+10	1.84E+10
Th232	9.65E-01	1.49E+00	2.54E+00	6.23E+00	5.38E+01	5.41E+02	6.27E+03	7.72E+04	7.76E+05
Pa231	6.80E+05	6.99E+05	7.31E+05	8.42E+05	2.27E+06	1.65E+07	1.54E+08	9.41E+08	1.15E+09

Table B.3: (cont.)

Nuclide	DISQ	1.0a	3.0a	10.0a	100.0a	1.0E03a	1.0E04a	1.0E05a	1.0E06a
U232	3.94E+08	5.35E+08	7.25E+08	9.29E+08	4.01E+08	6.14E+04	1.40E+04	9.34E+03	1.63E+02
U233	5.15E+05	5.73E+05	6.84E+05	1.05E+06	6.45E+06	1.17E+08	1.74E+09	1.47E+10	3.26E+10
U234	5.13E+10	5.15E+10	5.20E+10	5.37E+10	6.91E+10	8.38E+10	8.20E+10	6.63E+10	1.60E+10
U235	7.52E+08	7.52E+08	7.52E+08	7.52E+08	7.53E+08	7.63E+08	8.51E+08	1.13E+09	1.15E+09
U236	1.07E+10	1.07E+10	1.07E+10	1.07E+10	1.07E+10	1.12E+10	1.41E+10	1.60E+10	1.55E+10
U238	1.17E+10	1.17E+10	1.17E+10	1.17E+10	1.17E+10	1.17E+10	1.17E+10	1.17E+10	1.17E+10
Np237	1.18E+10	1.20E+10	1.21E+10	1.22E+10	1.57E+10	3.61E+10	4.23E+10	4.11E+10	3.07E+10
Pu238	8.32E+13	8.91E+13	8.92E+13	8.45E+13	4.16E+13	3.58E+10	2.93E-10	0.00E+00	0.00E+00
Pu239	1.13E+13	1.15E+13	1.15E+13	1.15E+13	1.14E+13	1.12E+13	8.68E+12	6.60E+11	1.87E+03
Pu240	1.88E+13	1.88E+13	1.88E+13	1.89E+13	1.88E+13	1.71E+13	6.61E+12	4.92E+08	1.09E+04
Pu241	4.40E+15	4.20E+15	3.81E+15	2.72E+15	3.52E+13	3.89E+09	1.87E+09	1.21E+06	0.00E+00
Pu242	5.82E+10	5.82E+10	5.82E+10	5.82E+10	5.82E+10	5.81E+10	5.72E+10	4.84E+10	9.17E+09
Am241	4.33E+12	1.12E+13	2.40E+13	5.98E+13	1.31E+14	3.13E+13	1.88E+09	1.28E+06	0.00E+00
Am242M	2.98E+11	2.97E+11	2.94E+11	2.84E+11	1.82E+11	2.18E+09	1.33E-10	0.00E+00	0.00E+00
Am243	5.28E+11	5.29E+11	5.29E+11	5.28E+11	5.24E+11	4.81E+11	2.07E+11	4.35E+07	1.87E+03
Cm244	5.58E+13	5.37E+13	4.98E+13	3.80E+13	1.21E+12	1.30E-03	0.00E+00	0.00E+00	0.00E+00
Cm245	4.21E+09	4.21E+09	4.21E+09	4.20E+09	4.17E+09	3.88E+09	1.86E+09	1.21E+06	0.00E+00
Cm246	7.82E+08	7.81E+08	7.81E+08	7.81E+08	7.70E+08	6.75E+08	1.81E+08	3.38E+02	0.00E+00
Total	4.06E+16	2.89E+16	1.77E+16	9.18E+15	8.82E+14	6.09E+13	1.64E+13	1.57E+12	3.47E+11
Alpha	1.74E+14	1.85E+14	1.94E+14	2.13E+14	2.05E+14	6.03E+13	1.57E+13	1.01E+12	2.06E+11
Beta/Gamma	4.05E+16	2.87E+16	1.75E+16	8.97E+15	6.77E+14	6.98E+11	6.65E+11	5.63E+11	1.41E+11

Table B.4: Nuclide activities ($Bq(t_{IHM})^{-1}$) calculated with ORIGEN2.1 for reference case 4 (TVF) from Table 2, at various decay times (DISQ = at time of discharge).

Nuclide	**DISQ**	**1.0a**	**3.0a**	**10.0a**	**100.0a**	**1.0E03a**	**1.0E04a**	**1.0E05a**	**1.0E06a**
H3	2.49E+13	2.35E+13	2.10E+13	1.42E+13	8.96E+10	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Be10	1.14E+05	1.14E+05	1.14E+05	1.14E+05	1.14E+05	1.14E+05	1.14E+05	1.09E+05	7.41E+04
C14	1.45E+10	1.45E+10	1.45E+10	1.45E+10	1.44E+10	1.29E+10	4.34E+09	8.11E+04	0.00E+00
Cl36	3.00E+08	3.00E+08	3.00E+08	3.00E+08	3.00E+08	3.00E+08	2.93E+08	2.38E+08	2.98E+07
Ca41	3.66E+06	3.66E+06	3.66E+06	3.66E+06	3.66E+06	3.64E+06	3.42E+06	1.87E+06	4.37E+03
Fe55	2.63E+11	2.04E+11	1.23E+11	2.08E+10	2.47E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co60	4.42E+12	3.87E+12	2.98E+12	1.19E+12	8.61E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni59	2.80E+08	2.80E+08	2.80E+08	2.80E+08	2.80E+08	2.77E+08	2.55E+08	1.11E+08	2.71E+04
Ni63	3.93E+10	3.90E+10	3.85E+10	3.67E+10	1.98E+10	4.11E+07	0.00E+00	0.00E+00	0.00E+00
Se79	7.74E+08	7.74E+08	7.74E+08	7.74E+08	7.74E+08	7.74E+08	7.70E+08	7.27E+08	4.13E+08
Kr85	3.25E+14	3.05E+14	2.68E+14	1.71E+14	5.18E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rb87	7.24E+05	7.24E+05	7.24E+05	7.24E+05	7.24E+05	7.24E+05	7.24E+05	7.24E+05	7.24E+05
Sr90	2.60E+15	2.54E+15	2.42E+15	2.04E+15	2.31E+14	8.02E+04	0.00E+00	0.00E+00	0.00E+00
Zr93	6.18E+10	6.18E+10	6.18E+10	6.18E+10	6.18E+10	6.18E+10	6.15E+10	5.90E+10	3.89E+10
Nb93M	2.84E+09	5.19E+09	9.60E+09	2.24E+10	5.80E+10	5.87E+10	5.84E+10	5.61E+10	3.70E+10
Nb94	3.51E+06	3.51E+06	3.51E+06	3.51E+06	3.50E+06	3.39E+06	2.48E+06	1.10E+05	3.12E-09
Mo93	1.38E+07	1.38E+07	1.38E+07	1.38E+07	1.36E+07	1.16E+07	2.44E+06	4.12E-01	0.00E+00
Tc99	4.32E+11	4.35E+11	4.34E+11	4.34E+11	4.34E+11	4.33E+11	4.20E+11	3.12E+11	1.60E+10
Ru106	1.43E+16	7.25E+15	1.87E+15	1.63E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pd107	2.58E+09	2.58E+09	2.58E+09	2.58E+09	2.58E+09	2.58E+09	2.57E+09	2.55E+09	2.32E+09
Ag108M	9.91E+07	9.90E+07	9.87E+07	9.75E+07	8.40E+07	1.89E+07	6.23E+00	0.00E+00	0.00E+00
Cd113M	1.30E+12	1.24E+12	1.13E+12	8.07E+11	1.13E+10	3.13E-09	0.00E+00	0.00E+00	0.00E+00
Sn121M	5.02E+09	4.96E+09	4.84E+09	4.43E+09	1.42E+09	1.69E+04	0.00E+00	0.00E+00	0.00E+00

Table B.4: (cont.)

Nuclide	DISQ	1.0a	3.0a	10.0a	100.0a	1.0E03a	1.0E04a	1.0E05a	1.0E06a
Sn126	9.02E+09	9.02E+09	9.02E+09	9.02E+09	9.02E+09	9.00E+09	8.76E+09	6.71E+09	4.69E+08
Sb125	4.02E+14	3.16E+14	1.92E+14	3.33E+13	5.51E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I129	9.23E+08	9.32E+08	9.32E+08	9.32E+08	9.32E+08	9.32E+08	9.32E+08	9.28E+08	8.92E+08
Cs134	3.82E+15	2.73E+15	1.39E+15	1.32E+14	9.32E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs135	1.33E+10	1.34E+10	1.34E+10	1.34E+10	1.34E+10	1.34E+10	1.33E+10	1.30E+10	9.88E+09
Cs137	3.26E+15	3.19E+15	3.04E+15	2.59E+15	3.28E+14	3.43E+05	0.00E+00	0.00E+00	0.00E+00
Pm147	5.38E+15	4.33E+15	2.55E+15	4.00E+14	1.83E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm147	4.49E+04	7.73E+04	1.21E+05	1.75E+05	1.84E+05	1.84E+05	1.84E+05	1.84E+05	1.84E+05
Sm151	1.30E+13	1.31E+13	1.29E+13	1.23E+13	6.28E+12	7.66E+09	0.00E+00	0.00E+00	0.00E+00
Eu152	2.60E+11	2.47E+11	2.23E+11	1.55E+11	1.44E+09	6.79E-12	0.00E+00	0.00E+00	0.00E+00
Eu154	1.94E+14	1.79E+14	1.53E+14	8.82E+13	7.36E+10	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Eu155	1.41E+14	1.22E+14	9.11E+13	3.29E+13	6.70E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ho166M	2.74E+07	2.74E+07	2.73E+07	2.72E+07	2.58E+07	1.54E+07	8.49E+04	0.00E+00	0.00E+00
Pb210	5.79E+01	8.98E+01	2.26E+02	2.26E+03	7.92E+05	1.41E+08	5.67E+09	4.41E+10	1.84E+10
Po210	1.18E+09	1.97E+08	5.07E+06	2.28E+03	7.92E+05	1.41E+08	5.67E+09	4.41E+10	1.84E+10
Ra226	6.70E+02	1.36E+03	3.51E+03	1.94E+04	1.42E+06	1.42E+08	5.67E+09	4.42E+10	1.84E+10
Ra228	6.06E-02	1.61E-01	5.02E-01	2.71E+00	5.37E+01	5.40E+02	6.08E+03	7.23E+04	7.25E+05
Ac227	1.20E+04	2.88E+04	6.32E+04	1.91E+05	2.30E+06	2.60E+07	2.41E+08	1.33E+09	1.59E+09
Th228	6.42E+07	1.36E+08	2.77E+08	5.36E+08	2.56E+08	4.04E+04	1.56E+04	7.86E+04	7.25E+05
Th229	3.80E+03	3.84E+03	3.96E+03	4.45E+03	2.75E+04	3.23E+06	4.21E+08	1.09E+10	2.40E+10
Th230	1.28E+06	1.89E+06	3.10E+06	7.39E+06	6.69E+07	7.57E+08	7.28E+09	4.41E+10	1.84E+10
Th232	6.75E-01	1.20E+00	2.26E+00	5.96E+00	5.37E+01	5.40E+02	6.08E+03	7.23E+04	7.25E+05
Pa231	5.32E+05	5.61E+05	6.12E+05	7.91E+05	3.10E+06	2.60E+07	2.41E+08	1.33E+09	1.59E+09

Table B.4: (cont.)

Nuclide	DISQ	1.0a	3.0a	10.0a	100.0a	1.0E03a	1.0E04a	1.0E05a	1.0E06a
U232	2.54E+08	3.39E+08	4.54E+08	5.77E+08	2.49E+08	3.90E+04	9.55E+03	6.36E+03	1.11E+02
U233	5.37E+05	5.81E+05	6.66E+05	9.50E+05	5.08E+06	8.72E+07	1.28E+09	1.08E+10	2.40E+10
U234	6.58E+10	6.59E+10	6.62E+10	6.71E+10	7.57E+10	8.38E+10	8.20E+10	6.62E+10	1.60E+10
U235	1.21E+09	1.21E+09	1.21E+09	1.21E+09	1.21E+09	1.22E+09	1.31E+09	1.57E+09	1.59E+09
U236	1.07E+10	1.07E+10	1.07E+10	1.07E+10	1.08E+10	1.11E+10	1.35E+10	1.49E+10	1.45E+10
U238	1.17E+10	1.17E+10	1.17E+10	1.17E+10	1.17E+10	1.17E+10	1.17E+10	1.17E+10	1.17E+10
Np237	9.04E+09	9.28E+09	9.28E+09	9.35E+09	1.19E+10	2.67E+10	3.11E+10	3.02E+10	2.26E+10
Pu238	4.67E+13	4.97E+13	4.96E+13	4.70E+13	2.31E+13	1.99E+10	1.60E-10	0.00E+00	0.00E+00
Pu239	1.08E+13	1.09E+13	1.09E+13	1.09E+13	1.09E+13	1.06E+13	8.24E+12	6.22E+11	2.08E+02
Pu240	1.50E+13	1.50E+13	1.50E+13	1.50E+13	1.49E+13	1.35E+13	5.23E+12	3.90E+08	3.40E+03
Pu241	3.20E+15	3.05E+15	2.77E+15	1.98E+15	2.56E+13	8.38E+08	4.02E+08	2.61E+05	0.00E+00
Pu242	3.03E+10	3.03E+10	3.03E+10	3.03E+10	3.03E+10	3.03E+10	2.98E+10	2.52E+10	4.78E+09
Am241	2.56E+12	7.56E+12	1.69E+13	4.29E+13	9.50E+13	2.26E+13	4.14E+08	2.75E+05	0.00E+00
Am242M	1.63E+11	1.62E+11	1.60E+11	1.55E+11	9.94E+10	1.19E+09	7.27E-11	0.00E+00	0.00E+00
Am243	2.01E+11	2.02E+11	2.02E+11	2.01E+11	2.00E+11	1.84E+11	7.87E+10	1.66E+07	2.05E+02
Cm244	1.51E+13	1.45E+13	1.35E+13	1.03E+13	3.28E+11	3.53E-04	0.00E+00	0.00E+00	0.00E+00
Cm245	9.08E+08	9.08E+08	9.08E+08	9.07E+08	9.01E+08	8.37E+08	4.02E+08	2.61E+05	0.00E+00
Cm246	1.17E+08	1.17E+08	1.17E+08	1.17E+08	1.16E+08	1.01E+08	2.71E+07	5.08E+01	0.00E+00
Total	3.37E+16	2.42E+16	1.49E+16	7.64E+15	7.36E+14	4.78E+13	1.43E+13	1.43E+12	3.02E+11
Alpha	9.06E+13	9.81E+13	1.06E+14	1.27E+14	1.45E+14	4.72E+13	1.37E+13	9.28E+11	1.76E+11
Beta/Gamma	3.37E+16	2.41E+16	1.48E+16	7.51E+15	5.92E+14	6.04E+11	5.78E+11	4.97E+11	1.26E+11

Appendix C

Table C.1: Comparison of nuclide activities ($Bq(t_{IHM})^{-1}$) calculated with 4 codes for reference case 1 (JNFL) from Table 2. Columns 2-5 present the calculated activities for each nuclide (at the time of discharge) and columns 6-8 present the ratio of the values of ORIGEN-ARP, OCTOPUS and BOXER to the ORIGEN2.1 value for ease of intercomparison.

Nuclide	**ORIGEN2.1**	**ORIGEN-ARP**	**OCTOPUS**	**BOXER**	**ORIGEN-ARP/2.1**	**OCTOPUS /2.1**	**BOXER/2.1**
H3	3.59E+13	3.39E+13	3.85E+13	3.90E+13	0.94	1.07	1.09
Be10	2.03E+05	3.01E+05	1.05E+07	1.04E+07	1.48	51.80	51.26
C14	1.92E+10	2.66E+10	6.32E+10	3.46E+10	1.38	3.29	1.80
Cl36	3.83E+08	4.52E+08	4.40E+08	4.82E+08	1.18	1.15	1.26
Ca41	4.74E+06	5.70E+06	5.80E+06	6.53E+06	1.20	1.22	1.38
Fe55	3.20E+11	3.48E+11	4.34E+11	5.15E+11	1.09	1.35	1.61
Co60	5.78E+12	5.44E+12	1.86E+10	4.95E+12	0.94	0.003	0.86
Ni59	3.53E+08	4.40E+08	4.34E+08	4.64E+08	1.25	1.23	1.32
Ni63	5.04E+10	6.14E+10	5.95E+10	6.16E+10	1.22	1.18	1.22
Se79	1.22E+09	1.01E+09	9.82E+08	9.94E+08	0.83	0.81	0.81
Kr85	4.81E+14	4.52E+14	5.28E+14	2.23E+15	0.94	1.10	4.64
Rb87	1.10E+06	1.07E+06	1.04E+06	1.04E+06	0.97	0.95	0.95
Sr90	3.88E+15	3.87E+15	3.93E+15	3.79E+15	1.00	1.01	0.98
Zr93	9.52E+10	6.13E+10	9.11E+10	9.13E+10	0.64	0.96	0.96
Nb93M	6.47E+09	4.28E+09	6.32E+09	6.12E+09	0.66	0.98	0.95
Nb94	6.39E+06	4.33E+06	1.19E+07	1.25E+07	0.68	1.86	1.96
Mo93	2.13E+07	4.20E+07	6.76E+07	8.41E+07	1.97	3.17	3.95
Tc99	6.63E+11	6.69E+11	6.88E+11	6.55E+11	1.01	1.04	0.99
Ru106	2.29E+16	2.43E+16	2.32E+16	2.35E+16	1.06	1.01	1.03
Pd107	5.04E+09	5.48E+09	5.14E+09	5.20E+09	1.09	1.02	1.03
Ag108M	1.37E+08	3.31E+08	2.98E+08	9.07E+07	2.41	2.18	0.66
Cd113M	2.52E+12	1.68E+12	2.56E+10	3.58E+12	0.66	0.01	1.42
Sn121M	8.77E+09	1.09E+11	1.22E+12	1.23E+11	12.48	138.62	14.03
Sn126	1.53E+10	1.11E+10	1.64E+10	1.62E+10	0.73	1.07	1.06
Sb125	6.23E+14	3.64E+14	6.31E+14	6.38E+14	0.58	1.01	1.02
I129	1.52E+09	1.56E+09	1.61E+09	1.53E+09	1.03	1.06	1.01
Cs134	8.68E+15	8.20E+15	8.97E+15	8.69E+15	0.94	1.03	1.00
Cs135	2.50E+10	2.39E+10	2.26E+10	2.34E+10	0.96	0.90	0.94
Cs137	5.18E+15	5.38E+15	5.41E+15	5.22E+15	1.04	1.04	1.01
Pm147	5.67E+15	7.32E+15	8.01E+15	7.17E+15	1.29	1.41	1.26
Sm147	7.44E+04	8.29E+04	8.75E+04	8.20E+04	1.11	1.18	1.10

Nuclide	**ORIGEN2.1**	**ORIGEN-ARP**	**OCTOPUS**	**BOXER**	**ORIGEN-ARP/2.1**	**OCTOPUS /2.1**	**BOXER/2.1**
Sm151	2.00E+13	1.96E+13	1.31E+13	1.63E+13	0.98	0.65	0.81
Eu152	4.11E+11	3.45E+11	2.46E+11	2.99E+11	0.84	0.60	0.73
Eu154	4.71E+14	3.39E+14	5.10E+14	5.10E+14	0.72	1.08	1.08
Eu155	3.36E+14	1.37E+14	1.97E+14	2.05E+14	0.41	0.59	0.61
Ho166M	1.02E+08	2.53E+07	0.00E+00	2.41E+08	0.25	0.00	2.37
Pb210	1.92E+02	2.78E+02	4.75E+01	7.90E+03	1.45	0.25	41.15
Po210	1.35E+09	2.38E+09	3.64E+09	3.53E+09	1.77	2.71	2.62
Ra226	1.42E+03	1.15E+03	1.25E+03	1.41E+03	0.81	0.88	1.00
Ra228	1.84E-01	1.90E-01	6.34E-01	1.78E-01	1.03	3.46	0.97
Ac227	3.19E+04	8.92E+04	2.00E+04	2.96E+04	2.80	0.63	0.93
Th228	1.61E+08	1.72E+08	1.19E+08	1.35E+08	1.07	0.74	0.84
Th229	1.08E+04	3.23E+03	1.03E+04	5.21E+03	0.30	0.95	0.48
Th230	1.69E+06	1.08E+06	1.53E+06	1.56E+06	0.64	0.91	0.92
Th232	1.41E+00	1.41E+00	1.64E+00	1.35E+00	1.01	1.17	0.96
Pa231	1.00E+06	2.03E+06	1.14E+06	1.11E+06	2.02	1.14	1.11
U232	6.57E+08	5.89E+08	4.93E+08	4.34E+08	0.90	0.75	0.66
U233	7.74E+05	1.16E+06	1.33E+06	1.14E+06	1.50	1.72	1.47
U234	5.97E+10	5.55E+10	5.44E+10	5.41E+10	0.93	0.91	0.91
U235	7.21E+08	8.56E+08	8.16E+08	8.82E+08	1.19	1.13	1.22
U236	1.44E+10	1.44E+10	1.44E+10	1.37E+10	1.00	1.00	0.95
U238	1.15E+10	1.15E+10	1.15E+10	1.15E+10	1.00	1.00	1.00
Np237	1.81E+10	1.78E+10	1.60E+10	2.15E+10	0.99	0.88	1.19
Pu238	1.46E+14	1.70E+14	1.52E+14	1.91E+14	1.16	1.04	1.31
Pu239	1.14E+13	1.35E+13	1.28E+13	1.37E+13	1.19	1.12	1.21
Pu240	2.12E+13	2.05E+13	2.08E+13	2.10E+13	0.97	0.98	0.99
Pu241	5.25E+15	6.20E+15	5.70E+15	5.95E+15	1.18	1.09	1.13
Pu242	8.20E+10	1.06E+11	9.21E+10	8.80E+10	1.30	1.12	1.07
Am241	4.61E+12	7.13E+12	5.91E+12	6.33E+12	1.55	1.28	1.37
Am242M	3.99E+11	4.77E+11	2.31E+11	4.22E+11	1.20	0.58	1.06
Am243	8.85E+11	1.31E+12	9.68E+11	9.61E+11	1.48	1.09	1.09
Cm244	1.15E+14	1.78E+14	1.38E+14	1.32E+14	1.55	1.20	1.15
Cm245	1.10E+10	1.46E+10	1.77E+10	1.49E+10	1.33	1.60	1.35
Cm246	1.99E+09	3.66E+09	3.36E+09	2.51E+09	1.84	1.68	1.26
Total	5.39E+16	5.70E+16	5.75E+16	5.83E+16	1.06	1.07	1.08
Alpha	3.00E+14	3.91E+14	3.31E+14	3.66E+14	1.30	1.10	1.22
Beta/Gamma	5.36E+16	5.66E+16	5.71E+16	5.80E+16	1.06	1.07	1.08

Table C.2: Comparison of nuclide activities ($Bq(t_{IHM})^{-1}$) calculated with 4 codes for reference case 2 (BNFL) from Table 2. Columns 2-5 present the calculated activities for each nuclide (at the time of discharge) and columns 6-8 present the ratio of the values of ORIGEN-ARP, OCTOPUS and BOXER to the ORIGEN2.1 value for ease of intercomparison.

Nuclide	ORIGEN2.1	ORIGEN-ARP	OCTOPUS	BOXER	ORIGEN-ARP/2.1	OCTOPUS /2.1	BOXER/2.1
H3	2.94E+13	2.70E+13	3.05E+13	3.12E+13	0.92	1.04	1.06
Be10	1.47E+05	2.20E+05	7.79E+06	7.70E+06	1.50	52.99	52.38
C14	2.02E+10	2.23E+10	5.36E+10	2.95E+10	1.10	2.65	1.46
Cl36	4.11E+08	3.84E+08	4.06E+08	4.46E+08	0.93	0.99	1.09
Ca41	5.09E+06	4.83E+06	5.23E+06	5.96E+06	0.95	1.03	1.17
Fe55	3.24E+11	2.87E+11	3.76E+11	4.43E+11	0.88	1.16	1.37
Co60	5.59E+12	4.56E+12	1.17E+10	4.21E+12	0.82	0.002	0.75
Ni59	3.75E+08	3.83E+08	4.04E+08	4.34E+08	1.02	1.08	1.16
Ni63	5.38E+10	5.18E+10	5.43E+10	5.69E+10	0.96	1.01	1.06
Se79	8.94E+08	7.42E+08	7.22E+08	7.27E+08	0.83	0.81	0.81
Kr85	3.43E+14	3.21E+14	3.82E+14	1.61E+15	0.94	1.11	4.69
Rb87	7.84E+05	7.61E+05	7.55E+05	7.58E+05	0.97	0.96	0.97
Sr90	2.76E+15	2.75E+15	2.85E+15	2.75E+15	1.00	1.03	1.00
Zr93	6.88E+10	4.44E+10	6.67E+10	6.69E+10	0.65	0.97	0.97
Nb93M	4.80E+09	3.17E+09	4.74E+09	4.60E+09	0.66	0.99	0.96
Nb94	5.17E+06	3.40E+06	7.32E+06	7.65E+06	0.66	1.42	1.48
Mo93	1.92E+07	3.54E+07	5.12E+07	6.31E+07	1.84	2.67	3.29
Tc99	4.95E+11	5.00E+11	5.15E+11	4.95E+11	1.01	1.04	1.00
Ru106	1.73E+16	1.82E+16	1.70E+16	1.72E+16	1.05	0.98	0.99
Pd107	3.99E+09	4.28E+09	3.88E+09	3.94E+09	1.07	0.97	0.99
Ag108M	1.35E+08	2.57E+08	2.20E+08	7.39E+07	1.90	1.63	0.55
Cd113M	1.90E+12	1.24E+12	2.04E+10	2.64E+12	0.65	0.01	1.39
Sn121M	6.82E+09	8.54E+10	9.25E+11	9.44E+10	12.52	135.62	13.84
Sn126	1.19E+10	8.60E+09	1.22E+10	1.21E+10	0.72	1.02	1.02
Sb125	4.81E+14	2.77E+14	4.70E+14	4.74E+14	0.58	0.98	0.99
I129	1.15E+09	1.18E+09	1.20E+09	1.14E+09	1.02	1.04	0.99
Cs134	5.39E+15	4.99E+15	5.42E+15	5.21E+15	0.93	1.01	0.97
Cs135	1.70E+10	1.98E+10	1.72E+10	1.77E+10	1.16	1.01	1.04
Cs137	3.80E+15	3.94E+15	3.97E+15	3.83E+15	1.04	1.04	1.01
Pm147	4.65E+15	6.02E+15	6.43E+15	5.92E+15	1.29	1.38	1.27
Sm147	6.17E+04	7.04E+04	7.48E+04	7.13E+04	1.14	1.21	1.16
Sm151	1.34E+13	1.62E+13	1.01E+13	1.20E+13	1.21	0.75	0.90
Eu152	2.99E+11	3.55E+11	2.24E+11	2.57E+11	1.19	0.75	0.86

Nuclide	ORIGEN2.1	ORIGEN-ARP	OCTOPUS	BOXER	ORIGEN-ARP/2.1	OCTOPUS /2.1	BOXER/2.1
Eu154	3.14E+14	2.29E+14	3.28E+14	3.20E+14	0.73	1.05	1.02
Eu155	2.15E+14	9.63E+13	1.29E+14	1.30E+14	0.45	0.60	0.60
Ho166M	7.21E+07	1.43E+07	0.00E+00	1.33E+08	0.20	0.00	1.84
Pb210	1.24E+02	1.77E+02	4.13E+01	4.12E+03	1.43	0.33	33.23
Po210	1.13E+09	1.81E+09	2.71E+09	2.64E+09	1.60	2.40	2.34
Ra226	1.17E+03	9.85E+02	1.09E+03	1.20E+03	0.84	0.93	1.03
Ra228	1.41E-01	1.44E-01	4.07E-01	1.37E-01	1.02	2.89	0.97
Ac227	2.35E+04	6.64E+04	1.61E+04	2.24E+04	2.83	0.68	0.95
Th228	1.19E+08	1.25E+08	8.71E+07	9.67E+07	1.05	0.73	0.81
Th229	7.78E+03	2.14E+03	7.10E+03	3.60E+03	0.28	0.91	0.46
Th230	1.41E+06	9.85E+05	1.34E+06	1.37E+06	0.70	0.95	0.97
Th232	1.04E+00	1.04E+00	1.19E+00	1.01E+00	1.00	1.14	0.97
Pa231	7.22E+05	1.51E+06	8.17E+05	7.93E+05	2.09	1.13	1.10
U232	4.26E+08	3.83E+08	3.09E+08	2.72E+08	0.90	0.73	0.64
U233	5.01E+05	8.81E+05	9.31E+05	7.53E+05	1.76	1.86	1.50
U234	4.84E+10	4.56E+10	4.54E+10	4.51E+10	0.94	0.94	0.93
U235	6.91E+08	8.00E+08	7.01E+08	7.47E+08	1.16	1.01	1.08
U236	1.03E+10	1.03E+10	1.03E+10	9.93E+09	1.00	1.00	0.96
U238	1.17E+10	1.17E+10	1.17E+10	1.17E+10	1.00	1.00	1.00
Np237	1.18E+10	1.18E+10	1.05E+10	1.34E+10	1.00	0.89	1.14
Pu238	8.75E+13	1.01E+14	8.56E+13	1.02E+14	1.15	0.98	1.17
Pu239	1.13E+13	1.36E+13	1.16E+13	1.23E+13	1.20	1.02	1.09
Pu240	1.91E+13	1.93E+13	1.82E+13	1.81E+13	1.01	0.95	0.95
Pu241	4.53E+15	5.43E+15	4.59E+15	4.72E+15	1.20	1.01	1.04
Pu242	6.22E+10	7.65E+10	6.57E+10	6.30E+10	1.23	1.06	1.01
Am241	4.91E+12	7.18E+12	5.30E+12	5.58E+12	1.46	1.08	1.14
Am242M	3.40E+11	4.66E+11	1.93E+11	3.42E+11	1.37	0.57	1.01
Am243	5.84E+11	7.83E+11	5.71E+11	5.58E+11	1.34	0.98	0.96
Cm244	6.39E+13	8.60E+13	6.32E+13	6.00E+13	1.35	0.99	0.94
Cm245	4.92E+09	6.33E+09	6.67E+09	5.47E+09	1.29	1.36	1.11
Cm246	9.49E+08	1.29E+09	1.06E+09	8.01E+08	1.36	1.11	0.84
Total	4.00E+16	4.25E+16	4.18E+16	4.24E+16	1.06	1.04	1.06
Alpha	1.88E+14	2.28E+14	1.85E+14	1.99E+14	1.21	0.98	1.06
Beta/Gamma	3.98E+16	4.23E+16	4.16E+16	4.22E+16	1.06	1.04	1.06

Table C.3: Comparison of nuclide activities ($Bq(t_{IHM})^{-1}$) calculated with 4 codes for reference case 3 (COGEMA) from Table 2. Columns 2-5 present the calculated activities for each nuclide (at the time of discharge) and columns 6-8 present the ratio of the values of ORIGEN-ARP, OCTOPUS and BOXER to the ORIGEN2.1 value for ease of intercomparison.

Nuclide	ORIGEN2.1	ORIGEN-ARP	OCTOPUS	BOXER	ORIGEN-ARP/2.1	OCTOPUS /2.1	BOXER/2.1
H3	2.93E+13	2.70E+13	3.03E+13	3.09E+13	0.92	1.03	1.05
Be10	1.45E+05	2.15E+05	7.76E+06	7.67E+06	1.48	53.54	52.90
C14	1.96E+10	2.18E+10	5.20E+10	2.86E+10	1.11	2.65	1.46
Cl36	3.99E+08	3.73E+08	3.90E+08	4.28E+08	0.93	0.98	1.07
Ca41	4.94E+06	4.67E+06	5.05E+06	5.72E+06	0.95	1.02	1.16
Fe55	3.26E+11	2.88E+11	3.76E+11	4.42E+11	0.88	1.15	1.36
Co60	5.55E+12	4.56E+12	1.16E+10	4.17E+12	0.82	0.002	0.75
Ni59	3.65E+08	3.71E+08	3.89E+08	4.18E+08	1.02	1.07	1.15
Ni63	5.23E+10	5.05E+10	5.22E+10	5.47E+10	0.97	1.00	1.05
Se79	8.97E+08	7.45E+08	7.25E+08	7.30E+08	0.83	0.81	0.81
Kr85	3.51E+14	3.29E+14	3.91E+14	1.65E+15	0.94	1.11	4.70
Rb87	7.95E+05	7.70E+05	7.61E+05	7.67E+05	0.97	0.96	0.96
Sr90	2.82E+15	2.80E+15	2.90E+15	2.79E+15	0.99	1.03	0.99
Zr93	6.95E+10	4.48E+10	6.72E+10	6.74E+10	0.64	0.97	0.97
Nb93M	4.39E+09	2.90E+09	4.33E+09	4.20E+09	0.66	0.99	0.96
Nb94	5.00E+06	3.34E+06	7.60E+06	7.97E+06	0.67	1.52	1.59
Mo93	1.86E+07	3.45E+07	5.05E+07	6.25E+07	1.86	2.72	3.36
Tc99	4.96E+11	5.02E+11	5.16E+11	4.97E+11	1.01	1.04	1.00
Ru106	1.77E+16	1.88E+16	1.75E+16	1.77E+16	1.06	0.99	1.00
Pd107	3.84E+09	4.15E+09	3.77E+09	3.82E+09	1.08	0.98	0.99
Ag108M	1.31E+08	2.48E+08	2.13E+08	7.18E+07	1.90	1.62	0.55
Cd113M	1.85E+12	1.22E+12	2.05E+10	2.60E+12	0.66	0.01	1.41
Sn121M	6.68E+09	8.36E+10	9.11E+11	9.19E+10	12.51	136.38	13.76
Sn126	1.16E+10	8.47E+09	1.20E+10	1.18E+10	0.73	1.03	1.02
Sb125	4.86E+14	2.81E+14	4.70E+14	4.76E+14	0.58	0.97	0.98
I129	1.14E+09	1.17E+09	1.19E+09	1.13E+09	1.03	1.04	0.99
Cs134	5.41E+15	5.08E+15	5.42E+15	5.27E+15	0.94	1.00	0.97
Cs135	1.62E+10	1.89E+10	1.67E+10	1.71E+10	1.17	1.03	1.06
Cs137	3.81E+15	3.97E+15	3.97E+15	3.84E+15	1.04	1.04	1.01
Pm147	4.86E+15	6.22E+15	6.67E+15	6.16E+15	1.28	1.37	1.27
Sm147	5.77E+04	6.58E+04	6.98E+04	6.65E+04	1.14	1.21	1.15
Sm151	1.35E+13	1.66E+13	1.04E+13	1.24E+13	1.23	0.77	0.92
Eu152	2.81E+11	3.36E+11	2.15E+11	2.47E+11	1.20	0.76	0.88

Nuclide	ORIGEN2.1	ORIGEN-ARP	OCTOPUS	BOXER	ORIGEN-ARP/2.1	OCTOPUS /2.1	BOXER/2.1
Eu154	3.06E+14	2.26E+14	3.21E+14	3.14E+14	0.74	1.05	1.03
Eu155	2.10E+14	9.53E+13	1.27E+14	1.30E+14	0.45	0.61	0.62
Ho166M	6.57E+07	1.32E+07	0.00E+00	1.22E+08	0.20	0.00	1.86
Pb210	1.08E+02	1.59E+02	3.19E+01	3.81E+03	1.47	0.30	35.28
Po210	1.21E+09	1.96E+09	2.94E+09	2.85E+09	1.62	2.43	2.36
Ra226	1.01E+03	8.49E+02	9.41E+02	1.03E+03	0.84	0.93	1.02
Ra228	1.18E-01	1.22E-01	3.54E-01	1.15E-01	1.04	3.00	0.97
Ac227	2.01E+04	5.65E+04	1.41E+04	1.94E+04	2.81	0.70	0.97
Th228	1.05E+08	1.10E+08	7.83E+07	8.69E+07	1.05	0.75	0.83
Th229	6.85E+03	1.87E+03	6.43E+03	3.23E+03	0.27	0.94	0.47
Th230	1.35E+06	9.54E+05	1.28E+06	1.30E+06	0.71	0.95	0.96
Th232	9.65E-01	9.67E-01	1.11E+00	9.34E-01	1.00	1.15	0.97
Pa231	6.80E+05	1.42E+06	7.75E+05	7.51E+05	2.09	1.14	1.10
U232	3.94E+08	3.55E+08	2.92E+08	2.56E+08	0.90	0.74	0.65
U233	5.15E+05	9.10E+05	9.74E+05	7.88E+05	1.77	1.89	1.53
U234	5.13E+10	4.82E+10	4.79E+10	4.77E+10	0.94	0.93	0.93
U235	7.52E+08	8.64E+08	7.73E+08	8.21E+08	1.15	1.03	1.09
U236	1.07E+10	1.06E+10	1.06E+10	1.02E+10	0.99	0.99	0.95
U238	1.17E+10	1.17E+10	1.17E+10	1.17E+10	1.00	1.00	1.00
Np237	1.18E+10	1.20E+10	1.06E+10	1.35E+10	1.02	0.90	1.14
Pu238	8.32E+13	9.76E+13	8.24E+13	9.97E+13	1.17	0.99	1.20
Pu239	1.13E+13	1.35E+13	1.16E+13	1.24E+13	1.19	1.03	1.10
Pu240	1.88E+13	1.82E+13	1.77E+13	1.78E+13	0.97	0.94	0.95
Pu241	4.40E+15	5.63E+15	4.55E+15	4.71E+15	1.28	1.04	1.07
Pu242	5.82E+10	7.41E+10	6.25E+10	5.98E+10	1.27	1.07	1.03
Am241	4.33E+12	6.58E+12	4.82E+12	5.08E+12	1.52	1.11	1.17
Am242M	2.98E+11	4.23E+11	1.78E+11	3.38E+11	1.42	0.60	1.13
Am243	5.28E+11	7.47E+11	5.37E+11	5.20E+11	1.41	1.02	0.98
Cm244	5.58E+13	8.00E+13	5.78E+13	5.47E+13	1.43	1.04	0.98
Cm245	4.21E+09	5.78E+09	6.00E+09	4.96E+09	1.37	1.43	1.18
Cm246	7.82E+08	1.11E+09	9.14E+08	6.90E+08	1.42	1.17	0.88
Total	4.06E+16	4.37E+16	4.25E+16	4.33E+16	1.08	1.05	1.07
Alpha	1.74E+14	2.17E+14	1.75E+14	1.90E+14	1.25	1.01	1.09
Beta/Gamma	4.05E+16	4.35E+16	4.23E+16	4.31E+16	1.07	1.04	1.06

Table C.4: Comparison of nuclide activities (Bq(t_{IHM})$^{-1}$) calculated with 4 codes for reference case 4 (TVF) from Table 2. Columns 2-5 present the calculated activities for each nuclide (at the time of discharge) and columns 6-8 present the ratio of the values of ORIGEN-ARP, OCTOPUS and BOXER to the ORIGEN2.1 value for ease of intercomparison.

Nuclide	ORIGEN2.1	ORIGEN-ARP	OCTOPUS	BOXER	ORIGEN-ARP/2.1	OCTOPUS /2.1	BOXER/2.1
H3	2.49E+13	2.33E+13	2.52E+13	2.56E+13	0.94	1.01	1.03
Be10	1.14E+05	1.59E+05	6.49E+06	6.39E+06	1.39	56.82	55.95
C14	1.45E+10	1.67E+10	3.92E+10	2.16E+10	1.15	2.69	1.49
Cl36	3.00E+08	2.88E+08	2.86E+08	3.15E+08	0.96	0.95	1.05
Ca41	3.66E+06	3.57E+06	3.67E+06	4.17E+06	0.98	1.00	1.14
Fe55	2.63E+11	2.41E+11	3.02E+11	3.59E+11	0.91	1.15	1.37
Co60	4.42E+12	3.74E+12	7.70E+09	3.34E+12	0.85	0.002	0.76
Ni59	2.80E+08	2.95E+08	2.92E+08	3.14E+08	1.05	1.04	1.12
Ni63	3.93E+10	3.89E+10	3.81E+10	4.01E+10	0.99	0.97	1.02
Se79	7.74E+08	6.44E+08	6.35E+08	6.33E+08	0.83	0.82	0.82
Kr85	3.25E+14	3.07E+14	3.62E+14	1.52E+15	0.94	1.11	4.68
Rb87	7.24E+05	7.04E+05	6.91E+05	6.92E+05	0.97	0.95	0.96
Sr90	2.60E+15	2.60E+15	2.67E+15	2.56E+15	1.00	1.03	0.98
Zr93	6.18E+10	3.99E+10	5.96E+10	5.95E+10	0.65	0.96	0.96
Nb93M	2.84E+09	1.89E+09	2.79E+09	2.70E+09	0.66	0.98	0.95
Nb94	3.51E+06	2.60E+06	6.46E+06	6.68E+06	0.74	1.84	1.90
Mo93	1.38E+07	2.65E+07	4.02E+07	5.02E+07	1.92	2.91	3.64
Tc99	4.32E+11	4.37E+11	4.50E+11	4.34E+11	1.01	1.04	1.00
Ru106	1.43E+16	1.57E+16	1.46E+16	1.49E+16	1.10	1.03	1.04
Pd107	2.58E+09	2.86E+09	2.63E+09	2.67E+09	1.11	1.02	1.04
Ag108M	9.91E+07	1.72E+08	1.47E+08	5.40E+07	1.74	1.49	0.54
Cd113M	1.30E+12	8.86E+11	1.99E+10	1.93E+12	0.68	0.02	1.49
Sn121M	5.02E+09	6.29E+10	6.96E+11	6.60E+10	12.53	138.69	13.15
Sn126	9.02E+09	6.41E+09	8.92E+09	8.82E+09	0.71	0.99	0.98
Sb125	4.02E+14	2.37E+14	3.69E+14	3.72E+14	0.59	0.92	0.93
I129	9.23E+08	9.61E+08	9.80E+08	9.32E+08	1.04	1.06	1.01
Cs134	3.82E+15	3.78E+15	4.01E+15	3.86E+15	0.99	1.05	1.01
Cs135	1.33E+10	1.54E+10	1.41E+10	1.46E+10	1.15	1.06	1.10
Cs137	3.26E+15	3.39E+15	3.43E+15	3.29E+15	1.04	1.05	1.01
Pm147	5.38E+15	6.46E+15	6.87E+15	6.40E+15	1.20	1.28	1.19
Sm147	4.49E+04	4.92E+04	5.15E+04	4.94E+04	1.10	1.15	1.10
Sm151	1.30E+13	1.64E+13	1.08E+13	1.28E+13	1.26	0.83	0.98
Eu152	2.60E+11	2.85E+11	2.08E+11	2.31E+11	1.10	0.80	0.89

Nuclide	ORIGEN2.1	ORIGEN-ARP	OCTOPUS	BOXER	ORIGEN-ARP/2.1	OCTOPUS /2.1	BOXER/2.1
Eu154	1.94E+14	1.57E+14	2.14E+14	2.07E+14	0.81	1.10	1.07
Eu155	1.41E+14	6.64E+13	9.45E+13	9.61E+13	0.47	0.67	0.68
Ho166M	2.74E+07	5.72E+06	0.00E+00	5.06E+07	0.21	0.00	1.85
Pb210	5.79E+01	9.10E+01	1.50E+01	2.28E+03	1.57	0.26	39.37
Po210	1.18E+09	2.01E+09	2.98E+09	2.94E+09	1.71	2.53	2.50
Ra226	6.70E+02	5.78E+02	6.26E+02	6.70E+02	0.86	0.93	1.00
Ra228	6.06E-02	6.28E-02	2.04E-01	5.94E-02	1.04	3.36	0.98
Ac227	1.20E+04	3.11E+04	9.59E+03	1.23E+04	2.58	0.80	1.02
Th228	6.42E+07	6.62E+07	5.25E+07	5.79E+07	1.03	0.82	0.90
Th229	3.80E+03	9.98E+02	3.99E+03	1.93E+03	0.26	1.05	0.51
Th230	1.28E+06	9.62E+05	1.21E+06	1.22E+06	0.75	0.94	0.95
Th232	6.75E-01	6.82E-01	8.33E-01	6.55E-01	1.01	1.23	0.97
Pa231	5.32E+05	1.13E+06	6.21E+05	5.97E+05	2.12	1.17	1.12
U232	2.54E+08	2.31E+08	2.08E+08	1.81E+08	0.91	0.82	0.71
U233	5.37E+05	9.74E+05	1.09E+06	8.57E+05	1.82	2.04	1.60
U234	6.58E+10	6.20E+10	6.18E+10	6.15E+10	0.94	0.94	0.94
U235	1.21E+09	1.30E+09	1.25E+09	1.31E+09	1.08	1.03	1.08
U236	1.07E+10	1.07E+10	1.06E+10	1.03E+10	1.00	0.99	0.96
U238	1.17E+10	1.17E+10	1.17E+10	1.17E+10	1.00	1.00	1.00
Np237	9.04E+09	9.74E+09	8.65E+09	1.10E+10	1.08	0.96	1.22
Pu238	4.67E+13	5.93E+13	5.10E+13	6.19E+13	1.27	1.09	1.32
Pu239	1.08E+13	1.29E+13	1.17E+13	1.26E+13	1.20	1.09	1.17
Pu240	1.50E+13	1.46E+13	1.40E+13	1.41E+13	0.97	0.94	0.94
Pu241	3.20E+15	4.63E+15	3.74E+15	3.83E+15	1.45	1.17	1.20
Pu242	3.03E+10	4.03E+10	3.52E+10	3.36E+10	1.33	1.16	1.11
Am241	2.56E+12	3.75E+12	3.11E+12	3.25E+12	1.47	1.22	1.27
Am242M	1.63E+11	2.37E+11	1.14E+11	2.00E+11	1.46	0.70	1.23
Am243	2.01E+11	3.19E+11	2.40E+11	2.28E+11	1.58	1.19	1.13
Cm244	1.51E+13	2.49E+13	1.94E+13	1.81E+13	1.65	1.29	1.20
Cm245	9.08E+08	1.47E+09	1.70E+09	1.40E+09	1.62	1.88	1.54
Cm246	1.17E+08	1.97E+08	1.74E+08	1.31E+08	1.68	1.48	1.12
Total	3.37E+16	3.75E+16	3.65E+16	3.72E+16	1.11	1.08	1.10
Alpha	9.06E+13	1.16E+14	9.98E+13	1.10E+14	1.28	1.10	1.21
Beta/Gamma	3.37E+16	3.74E+16	3.64E+16	3.71E+16	1.11	1.08	1.10

Appendix D

Table D.1: Comparison of nuclide activities ($Bq(t_{IHM})^{-1}$) calculated with 4 codes for the reference case 1, Table 2 (JNFL). Columns 2-5 present the calculated activities for each nuclide (at the time of discharge) and columns 6-8 present the ratio of the values of ORIGEN2.1, ORIGEN-ARP and OCTOPUS to the BOXER value for ease of intercomparison.

Nuclide	ORIGEN2.1	ORIGEN-ARP	OCTOPUS	BOXER	ORIGEN2.1 /BOXER	ORIGEN-ARP /BOXER	OCTOPUS /BOXER
H3	3.59E+13	3.39E+13	3.85E+13	3.90E+13	0.92	0.87	0.99
Be10	2.03E+05	3.01E+05	1.05E+07	1.04E+07	0.02	0.03	1.01
C14	1.92E+10	2.66E+10	6.32E+10	3.46E+10	0.56	0.77	1.83
Cl36	3.83E+08	4.52E+08	4.40E+08	4.82E+08	0.79	0.94	0.91
Ca41	4.74E+06	5.70E+06	5.80E+06	6.53E+06	0.73	0.87	0.89
Fe55	3.20E+11	3.48E+11	4.34E+11	5.15E+11	0.62	0.68	0.84
Co60	5.78E+12	5.44E+12	1.86E+10	4.95E+12	1.17	1.10	0.004
Ni59	3.53E+08	4.40E+08	4.34E+08	4.64E+08	0.76	0.95	0.93
Ni63	5.04E+10	6.14E+10	5.95E+10	6.16E+10	0.82	1.00	0.97
Se79	1.22E+09	1.01E+09	9.82E+08	9.94E+08	1.23	1.02	0.99
Kr85	4.81E+14	4.52E+14	5.28E+14	2.23E+15	0.22	0.20	0.24
Rb87	1.10E+06	1.07E+06	1.04E+06	1.04E+06	1.06	1.02	1.00
Sr90	3.88E+15	3.87E+15	3.93E+15	3.79E+15	1.02	1.02	1.04
Zr93	9.52E+10	6.13E+10	9.11E+10	9.13E+10	1.04	0.67	1.00
Nb93M	6.47E+09	4.28E+09	6.32E+09	6.12E+09	1.06	0.70	1.03
Nb94	6.39E+06	4.33E+06	1.19E+07	1.25E+07	0.51	0.35	0.95
Mo93	2.13E+07	4.20E+07	6.76E+07	8.41E+07	0.25	0.50	0.80
Tc99	6.63E+11	6.69E+11	6.88E+11	6.55E+11	1.01	1.02	1.05
Ru106	2.29E+16	2.43E+16	2.32E+16	2.35E+16	0.98	1.03	0.99
Pd107	5.04E+09	5.48E+09	5.14E+09	5.20E+09	0.97	1.05	0.99
Ag108M	1.37E+08	3.31E+08	2.98E+08	9.07E+07	1.51	3.65	3.29
Cd113M	2.52E+12	1.68E+12	2.56E+10	3.58E+12	0.70	0.47	0.01
Sn121M	8.77E+09	1.09E+11	1.22E+12	1.23E+11	0.07	0.89	9.88
Sn126	1.53E+10	1.11E+10	1.64E+10	1.62E+10	0.95	0.69	1.01
Sb125	6.23E+14	3.64E+14	6.31E+14	6.38E+14	0.98	0.57	0.99
I129	1.52E+09	1.56E+09	1.61E+09	1.53E+09	0.99	1.02	1.05
Cs134	8.68E+15	8.20E+15	8.97E+15	8.69E+15	1.00	0.94	1.03
Cs135	2.50E+10	2.39E+10	2.26E+10	2.34E+10	1.07	1.02	0.97
Cs137	5.18E+15	5.38E+15	5.41E+15	5.22E+15	0.99	1.03	1.04
Pm147	5.67E+15	7.32E+15	8.01E+15	7.17E+15	0.79	1.02	1.12
Sm147	7.44E+04	8.29E+04	8.75E+04	8.20E+04	0.91	1.01	1.07

Nuclide	ORIGEN2.1	ORIGEN-ARP	OCTOPUS	BOXER	ORIGEN2.1 /BOXER	ORIGEN-ARP /BOXER	OCTOPUS /BOXER
Sm151	2.00E+13	1.96E+13	1.31E+13	1.63E+13	1.23	1.20	0.80
Eu152	4.11E+11	3.45E+11	2.46E+11	2.99E+11	1.37	1.15	0.82
Eu154	4.71E+14	3.39E+14	5.10E+14	5.10E+14	0.92	0.66	1.00
Eu155	3.36E+14	1.37E+14	1.97E+14	2.05E+14	1.64	0.67	0.96
Ho166M	1.02E+08	2.53E+07	0.00E+00	2.41E+08	0.42	0.11	0.00
Pb210	1.92E+02	2.78E+02	4.75E+01	7.90E+03	0.02	0.04	0.01
Po210	1.35E+09	2.38E+09	3.64E+09	3.53E+09	0.38	0.67	1.03
Ra226	1.42E+03	1.15E+03	1.25E+03	1.41E+03	1.00	0.82	0.89
Ra228	1.84E-01	1.90E-01	6.34E-01	1.78E-01	1.03	1.07	3.56
Ac227	3.19E+04	8.92E+04	2.00E+04	2.96E+04	1.08	3.01	0.68
Th228	1.61E+08	1.72E+08	1.19E+08	1.35E+08	1.19	1.27	0.88
Th229	1.08E+04	3.23E+03	1.03E+04	5.21E+03	2.07	0.62	1.97
Th230	1.69E+06	1.08E+06	1.53E+06	1.56E+06	1.08	0.69	0.98
Th232	1.41E+00	1.41E+00	1.64E+00	1.35E+00	1.04	1.05	1.22
Pa231	1.00E+06	2.03E+06	1.14E+06	1.11E+06	0.90	1.83	1.03
U232	6.57E+08	5.89E+08	4.93E+08	4.34E+08	1.51	1.36	1.14
U233	7.74E+05	1.16E+06	1.33E+06	1.14E+06	0.68	1.02	1.16
U234	5.97E+10	5.55E+10	5.44E+10	5.41E+10	1.10	1.03	1.00
U235	7.21E+08	8.56E+08	8.16E+08	8.82E+08	0.82	0.97	0.93
U236	1.44E+10	1.44E+10	1.44E+10	1.37E+10	1.05	1.05	1.05
U238	1.15E+10	1.15E+10	1.15E+10	1.15E+10	1.00	1.00	1.00
Np237	1.81E+10	1.78E+10	1.60E+10	2.15E+10	0.84	0.83	0.74
Pu238	1.46E+14	1.70E+14	1.52E+14	1.91E+14	0.77	0.89	0.80
Pu239	1.14E+13	1.35E+13	1.28E+13	1.37E+13	0.83	0.99	0.93
Pu240	2.12E+13	2.05E+13	2.08E+13	2.10E+13	1.01	0.98	0.99
Pu241	5.25E+15	6.20E+15	5.70E+15	5.95E+15	0.88	1.04	0.96
Pu242	8.20E+10	1.06E+11	9.21E+10	8.80E+10	0.93	1.21	1.05
Am241	4.61E+12	7.13E+12	5.91E+12	6.33E+12	0.73	1.13	0.93
Am242M	3.99E+11	4.77E+11	2.31E+11	4.22E+11	0.95	1.13	0.55
Am243	8.85E+11	1.31E+12	9.68E+11	9.61E+11	0.92	1.36	1.01
Cm244	1.15E+14	1.78E+14	1.38E+14	1.32E+14	0.87	1.35	1.04
Cm245	1.10E+10	1.46E+10	1.77E+10	1.49E+10	0.74	0.98	1.19
Cm246	1.99E+09	3.66E+09	3.36E+09	2.51E+09	0.79	1.46	1.34
Total	5.39E+16	5.70E+16	5.75E+16	5.83E+16	0.92	0.98	0.99
Alpha	3.00E+14	3.91E+14	3.31E+14	3.66E+14	0.82	1.07	0.90
Beta/Gamma	5.36E+16	5.66E+16	5.71E+16	5.80E+16	0.92	0.98	0.98

Appendix E

Table E.1: Key parameter values for the 9 variations of reference case JNFL.

Case #, Label	Burnup [GWd $(t_{IHM})^{-1}$]	Enrichment [%]	Thermal power [MW $(t_{IHM})^{-1}$]
1, Bu28	28.0	4.5	38.00
2, Bu33	33.0	4.5	38.00
3, Bu55	55.0	4.5	38.00
4, En3.0	45.0	3.0	38.00
5, En3.5	45.0	3.5	38.00
6, En4.0	45.0	4.0	38.00
7, Po23	45.0	4.5	23.64
8, Po27	45.0	4.5	27.87
9, Po46	45.0	4.5	46.44

For the low burnup cases 1 (Bu28) and 2 (Bu33) the RWR-US cross section library was chosen in the ORIGEN2.1 calculations, corresponding to an ORIGEN2 reactor model designed to use UO_2 fuel with an enrichment of 3.2 % to achieve a standard burnup of 33 GWd$(t_{IHM})^{-1}$ (library maximum).

For all other (high burnup) cases 3-9 the RWR-UE cross section library was chosen in the ORIGEN2.1 calculations, corresponding to an ORIGEN2 reactor model designed to use UO_2 fuel with an enrichment of 4.2 % to achieve an extended burnup of 50 GWd$(t_{IHM})^{-1}$ (library maximum).

Table E.2: Nuclide densities for case # 4 corresponding to an enrichment of 3%.

Nuclide	Density [g $(t_{IHM})^{-1}$]
^{232}U	1.0E-04
^{234}U	300
^{235}U	30000
^{236}U	250
^{238}U	969450
^{16}O	134000

Table E.3: Nuclide densities for case # 5 corresponding to an enrichment of 3.5%.

Nuclide	Density [g $(t_{IHM})^{-1}$]
^{232}U	1.0E-04
^{234}U	350
^{235}U	35000
^{236}U	250
^{238}U	964400
^{16}O	134000

Table E.4: Nuclide densities for case # 6 corresponding to an enrichment of 4.0%.

Nuclide	**Density [g $(t_{IHM})^{-1}$]**
^{232}U	1.0E-04
^{234}U	400
^{235}U	40000
^{236}U	250
^{238}U	959350
^{16}O	134000

Appendix F

Table F.1: Nuclide activities $(Bq(t_{IHM})^{-1})$ calculated with **ORIGEN2.1** for reference case 1 (JNFL) from Tab. 2 and its 9 variants as listed in Tab. E.1, all at time of discharge.

Nuclide	**JNFL**	**Bu28**	**Bu33**	**Bu55**	**En3.0**	**En3.5**	**En4.0**	**Po23**	**Po27**	**Po46**
H3	3.59E+13	2.42E+13	2.80E+13	4.30E+13	3.89E+13	3.79E+13	3.68E+13	3.44E+13	3.50E+13	3.63E+13
Be10	2.03E+05	1.11E+05	1.35E+05	2.70E+05	2.38E+05	2.24E+05	2.13E+05	2.03E+05	2.03E+05	2.03E+05
C14	1.92E+10	1.32E+10	1.61E+10	2.52E+10	2.53E+10	2.31E+10	2.11E+10	1.92E+10	1.92E+10	1.92E+10
Cl36	3.83E+08	2.73E+08	3.30E+08	4.95E+08	4.97E+08	4.56E+08	4.17E+08	3.83E+08	3.83E+08	3.83E+08
Ca41	4.74E+06	3.32E+06	4.04E+06	6.22E+06	6.25E+06	5.70E+06	5.19E+06	4.74E+06	4.74E+06	4.74E+06
Fe55	3.20E+11	2.43E+11	2.86E+11	3.97E+11	4.18E+11	3.83E+11	3.51E+11	2.67E+11	2.86E+11	3.40E+11
Co60	5.78E+12	4.07E+12	4.80E+12	7.12E+12	7.36E+12	6.80E+12	6.28E+12	5.18E+12	5.41E+12	5.98E+12
Ni59	3.53E+08	2.56E+08	3.06E+08	4.45E+08	4.47E+08	4.13E+08	3.82E+08	3.53E+08	3.53E+08	3.53E+08
Ni63	5.04E+10	3.57E+10	4.32E+10	6.54E+10	6.57E+10	6.02E+10	5.51E+10	5.01E+10	5.02E+10	5.05E+10
Se79	1.22E+09	7.79E+08	9.11E+08	1.46E+09	1.18E+09	1.20E+09	1.21E+09	1.22E+09	1.22E+09	1.22E+09
Kr85	4.81E+14	3.36E+14	3.83E+14	5.47E+14	4.24E+14	4.45E+14	4.64E+14	4.50E+14	4.62E+14	4.90E+14
Rb87	1.10E+06	7.46E+05	8.58E+05	1.27E+06	9.50E+05	1.01E+06	1.06E+06	1.10E+06	1.10E+06	1.10E+06
Sr90	3.88E+15	2.69E+15	3.08E+15	4.44E+15	3.33E+15	3.53E+15	3.72E+15	3.79E+15	3.82E+15	3.91E+15
Zr93	9.52E+10	6.30E+10	7.30E+10	1.12E+11	8.67E+10	8.98E+10	9.27E+10	9.52E+10	9.52E+10	9.52E+10
Nb93M	6.47E+09	2.66E+09	3.63E+09	9.32E+09	6.05E+09	6.21E+09	6.35E+09	1.00E+10	8.63E+09	5.36E+09
Nb94	6.39E+06	3.14E+06	4.02E+06	8.58E+06	8.46E+06	7.71E+06	7.02E+06	6.40E+06	6.40E+06	6.39E+06
Mo93	2.13E+07	1.25E+07	1.53E+07	2.80E+07	2.81E+07	2.56E+07	2.34E+07	2.13E+07	2.13E+07	2.13E+07
Tc99	6.63E+11	4.35E+11	5.05E+11	7.79E+11	6.41E+11	6.48E+11	6.56E+11	6.63E+11	6.63E+11	6.63E+11
Ru106	2.29E+16	1.32E+16	1.60E+16	2.88E+16	3.08E+16	2.80E+16	2.54E+16	1.69E+16	1.89E+16	2.55E+16
Pd107	5.04E+09	2.27E+09	2.97E+09	7.15E+09	7.11E+09	6.35E+09	5.66E+09	5.04E+09	5.04E+09	5.05E+09
Ag108M	1.37E+08	9.02E+07	1.09E+08	1.76E+08	1.77E+08	1.62E+08	1.49E+08	1.37E+08	1.37E+08	1.37E+08
Cd113M	2.52E+12	1.18E+12	1.50E+12	3.64E+12	3.55E+12	3.15E+12	2.81E+12	2.43E+12	2.47E+12	2.55E+12
Sn121M	8.77E+09	4.70E+09	5.82E+09	1.15E+10	1.07E+10	9.98E+09	9.34E+09	8.68E+09	8.72E+09	8.79E+09

Table F.1: (cont.)

Nuclide	JNFL	Bu28	Bu33	Bu55	En3.0	En3.5	En4.0	Po23	Po27	Po46
Sn126	1.53E+10	8.55E+09	1.04E+10	1.97E+10	1.81E+10	1.71E+10	1.61E+10	1.53E+10	1.53E+10	1.53E+10
Sb125	6.23E+14	3.83E+14	4.52E+14	7.58E+14	7.53E+14	7.06E+14	6.63E+14	5.20E+14	5.58E+14	6.59E+14
I129	1.52E+09	8.98E+08	1.07E+09	1.88E+09	1.65E+09	1.60E+09	1.56E+09	1.52E+09	1.52E+09	1.51E+09
Cs134	8.68E+15	3.57E+15	4.90E+15	1.26E+16	1.04E+16	9.82E+15	9.26E+15	7.47E+15	7.92E+15	9.10E+15
Cs135	2.50E+10	1.34E+10	1.56E+10	2.99E+10	2.14E+10	2.25E+10	2.37E+10	3.31E+10	3.02E+10	2.20E+10
Cs137	5.18E+15	3.26E+15	3.83E+15	6.28E+15	5.19E+15	5.19E+15	5.18E+15	5.07E+15	5.11E+15	5.21E+15
Pm147	5.67E+15	5.77E+15	5.81E+15	5.18E+15	4.65E+15	4.95E+15	5.30E+15	5.01E+15	5.26E+15	5.89E+15
Sm147	7.44E+04	4.40E+04	5.37E+04	8.37E+04	5.83E+04	6.35E+04	6.89E+04	1.09E+05	9.60E+04	6.26E+04
Sm151	2.00E+13	1.34E+13	1.42E+13	2.19E+13	1.96E+13	1.97E+13	1.98E+13	1.94E+13	1.96E+13	2.03E+13
Eu152	4.11E+11	2.69E+11	2.81E+11	4.04E+11	3.19E+11	3.43E+11	3.73E+11	6.26E+11	5.42E+11	3.43E+11
Eu154	4.71E+14	1.73E+14	2.49E+14	7.00E+14	6.01E+14	5.57E+14	5.13E+14	4.58E+14	4.63E+14	4.74E+14
Eu155	3.36E+14	1.28E+14	1.74E+14	5.01E+14	4.37E+14	4.02E+14	3.68E+14	3.22E+14	3.28E+14	3.40E+14
Ho166M	1.02E+08	2.07E+07	3.65E+07	2.38E+08	2.41E+08	1.80E+08	1.35E+08	1.02E+08	1.02E+08	1.02E+08
Pb210	1.92E+02	5.12E+01	7.66E+01	3.71E+02	2.13E+02	2.07E+02	1.99E+02	4.07E+02	3.03E+02	1.52E+02
Po210	1.35E+09	1.15E+09	1.24E+09	1.54E+09	1.69E+09	1.57E+09	1.46E+09	8.71E+08	1.02E+09	1.60E+09
Ra226	1.42E+03	6.56E+02	8.66E+02	1.86E+03	8.19E+02	1.01E+03	1.21E+03	3.65E+03	2.63E+03	9.47E+02
Ra228	1.84E-01	5.37E-02	8.26E-02	3.00E-01	1.49E-01	1.63E-01	1.74E-01	4.47E-01	3.29E-01	1.25E-01
Ac227	3.19E+04	1.13E+04	1.61E+04	4.46E+04	2.02E+04	2.42E+04	2.81E+04	8.11E+04	5.87E+04	2.14E+04
Th228	1.61E+08	5.92E+07	7.92E+07	2.71E+08	1.54E+08	1.58E+08	1.60E+08	3.18E+08	2.51E+08	1.21E+08
Th229	1.08E+04	3.34E+03	4.87E+03	2.02E+04	1.17E+04	1.15E+04	1.12E+04	1.96E+04	1.59E+04	8.39E+03
Th230	1.69E+06	1.37E+06	1.50E+06	1.71E+06	9.32E+05	1.17E+06	1.42E+06	2.72E+06	2.31E+06	1.38E+06
Th232	1.41E+00	6.50E-01	8.56E-01	1.89E+00	1.09E+00	1.21E+00	1.32E+00	2.26E+00	1.92E+00	1.15E+00
Pa231	1.00E+06	5.37E+05	6.73E+05	1.20E+06	6.35E+05	7.61E+05	8.84E+05	1.61E+06	1.37E+06	8.20E+05

Table F.1: (cont.)

Nuclide	JNFL	Bu28	Bu33	Bu55	En3.0	En3.5	En4.0	Po23	Po27	Po46
U232	6.57E+08	2.38E+08	3.25E+08	1.07E+09	6.49E+08	6.62E+08	6.64E+08	9.66E+08	8.45E+08	5.60E+08
U233	7.74E+05	5.80E+05	6.22E+05	7.85E+05	5.19E+05	6.07E+05	6.92E+05	8.23E+05	8.03E+05	7.59E+05
U234	5.97E+10	7.64E+10	7.14E+10	5.04E+10	3.36E+10	4.16E+10	5.04E+10	5.99E+10	5.98E+10	5.96E+10
U235	7.21E+08	1.49E+09	1.23E+09	4.33E+08	2.89E+08	4.05E+08	5.49E+08	7.21E+08	7.21E+08	7.20E+08
U236	1.44E+10	1.14E+10	1.26E+10	1.50E+10	1.01E+10	1.17E+10	1.31E+10	1.44E+10	1.44E+10	1.44E+10
U238	1.15E+10	1.17E+10	1.17E+10	1.14E+10	1.16E+10	1.16E+10	1.16E+10	1.15E+10	1.15E+10	1.15E+10
Np237	1.81E+10	8.66E+09	1.12E+10	2.35E+10	1.69E+10	1.76E+10	1.80E+10	1.82E+10	1.82E+10	1.80E+10
Pu238	1.46E+14	4.01E+13	6.29E+13	2.44E+14	1.80E+14	1.72E+14	1.60E+14	1.57E+14	1.53E+14	1.43E+14
Pu239	1.14E+13	1.05E+13	1.10E+13	1.14E+13	1.15E+13	1.15E+13	1.14E+13	1.14E+13	1.14E+13	1.13E+13
Pu240	2.12E+13	1.38E+13	1.66E+13	2.32E+13	2.33E+13	2.27E+13	2.20E+13	2.12E+13	2.12E+13	2.12E+13
Pu241	5.25E+15	2.78E+15	3.53E+15	6.26E+15	6.27E+15	5.98E+15	5.63E+15	5.18E+15	5.21E+15	5.27E+15
Pu242	8.20E+10	2.34E+10	3.66E+10	1.31E+11	1.34E+11	1.15E+11	9.78E+10	8.16E+10	8.17E+10	8.21E+10
Am241	4.61E+12	2.08E+12	2.85E+12	5.62E+12	5.11E+12	4.98E+12	4.81E+12	7.31E+12	6.24E+12	3.79E+12
Am242M	3.99E+11	1.28E+11	1.86E+11	5.11E+11	4.61E+11	4.45E+11	4.24E+11	6.32E+11	5.39E+11	3.28E+11
Am243	8.85E+11	1.40E+11	2.70E+11	1.82E+12	1.90E+12	1.50E+12	1.16E+12	8.83E+11	8.84E+11	8.86E+11
Cm244	1.15E+14	9.36E+12	2.26E+13	3.23E+14	3.48E+14	2.44E+14	1.68E+14	1.14E+14	1.14E+14	1.16E+14
Cm245	1.10E+10	5.21E+08	1.47E+09	3.69E+10	4.03E+10	2.66E+10	1.72E+10	1.09E+10	1.10E+10	1.11E+10
Cm246	1.99E+09	6.01E+07	2.16E+08	9.31E+09	1.04E+10	6.06E+09	3.49E+09	1.98E+09	1.98E+09	2.00E+09
Total	5.39E+16	3.24E+16	3.85E+16	6.68E+16	6.34E+16	6.01E+16	5.69E+16	4.55E+16	4.84E+16	5.72E+16
Alpha	3.00E+14	7.62E+13	1.16E+14	6.09E+14	5.71E+14	4.57E+14	3.68E+14	3.11E+14	3.07E+14	2.96E+14
Beta/Gamma	5.36E+16	3.24E+16	3.84E+16	6.62E+16	6.28E+16	5.96E+16	5.65E+16	4.52E+16	4.81E+16	5.69E+16

Table F.2: Nuclide activities (Bq$(t_{IHM})^{-1}$) calculated with **BOXER** for reference case 1 (JNFL) from Table 2 and its 9 variants as listed in Table E.1, all at time of discharge.

Nuclide	JNFL	Bu28	Bu33	Bu55	En3.0	En3.5	En4.0	Po23	Po27	Po46
H3	3.90E+13	2.48E+13	2.90E+13	4.73E+13	4.21E+13	4.11E+13	4.00E+13	3.87E+13	3.89E+13	3.91E+13
Be10	1.04E+07	6.32E+06	7.51E+06	1.27E+07	1.07E+07	1.06E+07	1.05E+07	1.04E+07	1.04E+07	1.04E+07
C14	3.46E+10	1.99E+10	2.40E+10	4.45E+10	4.60E+10	4.14E+10	3.77E+10	3.47E+10	3.47E+10	3.46E+10
Cl36	4.82E+08	2.81E+08	3.37E+08	6.16E+08	6.96E+08	6.11E+08	5.40E+08	4.84E+08	4.83E+08	4.81E+08
Ca41	6.53E+06	3.72E+06	4.49E+06	8.47E+06	9.54E+06	8.32E+06	7.33E+06	6.55E+06	6.54E+06	6.52E+06
Fe55	5.15E+11	3.34E+11	3.87E+11	6.23E+11	7.07E+11	6.30E+11	5.67E+11	4.27E+11	4.59E+11	5.46E+11
Co60	4.95E+12	3.12E+12	3.66E+12	6.03E+12	6.44E+12	5.86E+12	5.36E+12	4.43E+12	4.63E+12	5.12E+12
Ni59	4.64E+08	2.82E+08	3.34E+08	5.77E+08	6.46E+08	5.75E+08	5.15E+08	4.66E+08	4.65E+08	4.63E+08
Ni63	6.16E+10	3.58E+10	4.29E+10	7.90E+10	8.96E+10	7.84E+10	6.92E+10	6.14E+10	6.15E+10	6.16E+10
Se79	9.94E+08	6.38E+08	7.45E+08	1.19E+09	9.54E+08	9.70E+08	9.83E+08	9.94E+08	9.94E+08	9.94E+08
Kr85	2.23E+15	1.56E+15	1.78E+15	2.53E+15	1.98E+15	2.08E+15	2.16E+15	2.09E+15	2.14E+15	2.27E+15
Rb87	1.04E+06	7.08E+05	8.13E+05	1.22E+06	9.26E+05	9.72E+05	1.01E+06	1.05E+06	1.05E+06	1.04E+06
Sr90	3.79E+15	2.63E+15	3.00E+15	4.36E+15	3.32E+15	3.51E+15	3.66E+15	3.70E+15	3.74E+15	3.82E+15
Zr93	9.13E+10	6.03E+10	6.98E+10	1.08E+11	8.49E+10	8.74E+10	8.95E+10	9.13E+10	9.13E+10	9.13E+10
Nb93M	6.12E+09	2.52E+09	3.43E+09	8.84E+09	5.80E+09	5.93E+09	6.03E+09	9.56E+09	8.20E+09	5.06E+09
Nb94	1.25E+07	6.71E+06	8.35E+06	1.62E+07	1.45E+07	1.38E+07	1.31E+07	9.35E+06	1.03E+07	1.43E+07
Mo93	8.41E+07	4.89E+07	5.88E+07	1.07E+08	9.36E+07	8.99E+07	8.68E+07	8.38E+07	8.39E+07	8.43E+07
Tc99	6.55E+11	4.36E+11	5.05E+11	7.66E+11	6.32E+11	6.40E+11	6.48E+11	6.56E+11	6.56E+11	6.55E+11
Ru106	2.35E+16	1.43E+16	1.70E+16	2.86E+16	3.01E+16	2.76E+16	2.54E+16	1.70E+16	1.92E+16	2.63E+16
Pd107	5.20E+09	2.44E+09	3.17E+09	7.17E+09	6.88E+09	6.23E+09	5.67E+09	5.18E+09	5.18E+09	5.21E+09
Ag108M	9.07E+07	5.01E+07	6.10E+07	1.20E+08	1.19E+08	1.08E+08	9.83E+07	9.05E+07	9.06E+07	9.08E+07
Cd113M	3.58E+12	1.82E+12	2.29E+12	4.81E+12	4.50E+12	4.14E+12	3.83E+12	3.43E+12	3.49E+12	3.63E+12
Sn121M	1.23E+11	6.07E+10	7.76E+10	1.65E+11	1.57E+11	1.44E+11	1.33E+11	1.21E+11	1.22E+11	1.23E+11

Table F.2: (cont.)

Nuclide	JNFL	Bu28	Bu33	Bu55	En3.0	En3.5	En4.0	Po23	Po27	Po46
Sn126	1.62E+10	8.34E+09	1.05E+10	2.16E+10	1.98E+10	1.84E+10	1.72E+10	1.61E+10	1.62E+10	1.62E+10
Sb125	6.38E+14	3.53E+14	4.35E+14	8.13E+14	8.01E+14	7.39E+14	6.85E+14	5.40E+14	5.76E+14	6.73E+14
I129	1.53E+09	9.19E+08	1.10E+09	1.91E+09	1.62E+09	1.59E+09	1.56E+09	1.53E+09	1.53E+09	1.54E+09
Cs134	8.69E+15	3.74E+15	5.04E+15	1.21E+16	9.91E+15	9.48E+15	9.07E+15	7.45E+15	7.91E+15	9.12E+15
Cs135	2.34E+10	1.51E+10	1.76E+10	2.80E+10	1.78E+10	1.96E+10	2.14E+10	3.10E+10	2.82E+10	2.05E+10
Cs137	5.22E+15	3.30E+15	3.87E+15	6.33E+15	5.22E+15	5.22E+15	5.22E+15	5.11E+15	5.15E+15	5.26E+15
Pm147	7.17E+15	6.69E+15	6.98E+15	7.00E+15	6.19E+15	6.53E+15	6.86E+15	6.22E+15	6.58E+15	7.50E+15
Sm147	8.20E+04	4.72E+04	5.85E+04	9.59E+04	6.93E+04	7.39E+04	7.81E+04	1.19E+05	1.05E+05	6.91E+04
Sm151	1.63E+13	1.39E+13	1.47E+13	1.74E+13	1.35E+13	1.44E+13	1.53E+13	1.55E+13	1.58E+13	1.67E+13
Eu152	2.99E+11	2.45E+11	2.69E+11	3.04E+11	1.89E+11	2.22E+11	2.60E+11	4.51E+11	3.92E+11	2.56E+11
Eu154	5.10E+14	1.92E+14	2.73E+14	7.30E+14	6.16E+14	5.75E+14	5.40E+14	4.95E+14	5.01E+14	5.16E+14
Eu155	2.05E+14	9.34E+13	1.23E+14	2.85E+14	2.37E+14	2.19E+14	2.11E+14	1.97E+14	2.00E+14	2.12E+14
Ho166M	2.41E+08	3.98E+07	7.36E+07	5.24E+08	5.24E+08	3.98E+08	3.07E+08	2.37E+08	2.39E+08	2.43E+08
Pb210	7.90E+03	2.24E+03	3.50E+03	1.31E+04	5.89E+03	6.62E+03	7.29E+03	1.29E+04	1.09E+04	6.40E+03
Po210	3.53E+09	3.00E+09	3.16E+09	3.84E+09	4.23E+09	3.96E+09	3.73E+09	2.25E+09	2.63E+09	4.25E+09
Ra226	1.41E+03	6.49E+02	8.58E+02	1.89E+03	8.56E+02	1.04E+03	1.22E+03	3.64E+03	2.62E+03	9.42E+02
Ra228	1.78E-01	5.28E-02	8.10E-02	2.89E-01	1.44E-01	1.57E-01	1.68E-01	4.32E-01	3.19E-01	1.21E-01
Ac227	2.96E+04	1.20E+04	1.69E+04	3.90E+04	1.57E+04	2.01E+04	2.48E+04	7.51E+04	5.45E+04	2.00E+04
Th228	1.35E+08	5.49E+07	7.17E+07	2.18E+08	1.12E+08	1.21E+08	1.28E+08	2.60E+08	2.07E+08	1.03E+08
Th229	5.21E+03	1.78E+03	2.52E+03	8.98E+03	5.32E+03	5.29E+03	5.25E+03	8.92E+03	7.40E+03	4.17E+03
Th230	1.56E+06	1.29E+06	1.41E+06	1.59E+06	8.97E+05	1.11E+06	1.33E+06	2.52E+06	2.13E+06	1.28E+06
Th232	1.35E+00	6.33E-01	8.28E-01	1.81E+00	1.06E+00	1.17E+00	1.26E+00	2.17E+00	1.84E+00	1.10E+00
Pa231	1.11E+06	6.17E+05	7.69E+05	1.32E+06	6.78E+05	8.21E+05	9.64E+05	1.77E+06	1.50E+06	9.06E+05

Table F.2: (cont.)

Nuclide	JNFL	Bu28	Bu33	Bu55	En3.0	En3.5	En4.0	Po23	Po27	Po46
U232	4.34E+08	1.79E+08	2.36E+08	6.59E+08	3.56E+08	3.87E+08	4.12E+08	6.50E+08	5.64E+08	3.67E+08
U233	1.14E+06	9.77E+05	1.05E+06	1.13E+06	6.46E+05	8.03E+05	9.70E+05	1.20E+06	1.17E+06	1.13E+06
U234	5.41E+10	7.10E+10	6.58E+10	4.54E+10	3.04E+10	3.79E+10	4.58E+10	5.44E+10	5.43E+10	5.40E+10
U235	8.82E+08	1.62E+09	1.37E+09	5.81E+08	3.11E+08	4.69E+08	6.61E+08	8.78E+08	8.79E+08	8.84E+08
U236	1.37E+10	1.09E+10	1.20E+10	1.43E+10	9.74E+09	1.12E+10	1.25E+10	1.37E+10	1.37E+10	1.36E+10
U238	1.15E+10	1.17E+10	1.16E+10	1.14E+10	1.16E+10	1.16E+10	1.16E+10	1.15E+10	1.15E+10	1.15E+10
Np237	2.15E+10	1.12E+10	1.42E+10	2.71E+10	1.82E+10	1.96E+10	2.06E+10	2.15E+10	2.15E+10	2.15E+10
Pu238	1.91E+14	5.82E+13	8.86E+13	3.03E+14	2.00E+14	1.99E+14	1.96E+14	2.02E+14	1.98E+14	1.88E+14
Pu239	1.37E+13	1.29E+13	1.34E+13	1.35E+13	1.19E+13	1.25E+13	1.31E+13	1.37E+13	1.37E+13	1.38E+13
Pu240	2.10E+13	1.31E+13	1.57E+13	2.43E+13	2.33E+13	2.26E+13	2.18E+13	2.12E+13	2.11E+13	2.09E+13
Pu241	5.95E+15	3.65E+15	4.45E+15	6.71E+15	5.92E+15	5.97E+15	5.98E+15	5.81E+15	5.86E+15	6.00E+15
Pu242	8.80E+10	2.82E+10	4.27E+10	1.33E+11	1.34E+11	1.16E+11	1.01E+11	8.70E+10	8.73E+10	8.85E+10
Am241	6.33E+12	2.91E+12	3.99E+12	7.55E+12	5.43E+12	5.80E+12	6.10E+12	9.90E+12	8.49E+12	5.23E+12
Am242M	4.22E+11	1.80E+11	2.56E+11	5.01E+11	3.41E+11	3.75E+11	4.08E+11	6.49E+11	5.58E+11	3.50E+11
Am243	9.61E+11	1.81E+11	3.31E+11	1.79E+12	1.72E+12	1.41E+12	1.16E+12	9.48E+11	9.52E+11	9.68E+11
Cm244	1.32E+14	1.35E+13	3.04E+13	3.25E+14	3.02E+14	2.26E+14	1.72E+14	1.28E+14	1.30E+14	1.34E+14
Cm245	1.49E+10	1.01E+09	2.66E+09	4.16E+10	3.44E+10	2.57E+10	1.95E+10	1.43E+10	1.45E+10	1.52E+10
Cm246	2.51E+09	8.25E+07	2.74E+08	1.00E+10	9.30E+09	5.89E+09	3.80E+09	2.44E+09	2.47E+09	2.55E+09
Total	5.83E+16	3.66E+16	4.32E+16	7.02E+16	6.49E+16	6.24E+16	6.02E+16	4.91E+16	5.23E+16	6.21E+16
Alpha	3.66E+14	1.01E+14	1.53E+14	6.75E+14	5.44E+14	4.68E+14	4.10E+14	3.76E+14	3.72E+14	3.63E+14
Beta/Gamma	5.80E+16	3.65E+16	4.30E+16	6.96E+16	6.43E+16	6.20E+16	5.98E+16	4.87E+16	5.19E+16	6.17E+16

Table F.3: Nuclide activities ($Bq(t_{IHM})^{-1}$) calculated with ORIGEN2.1 for reference case 1 (JNFL) from Table 2 and the ratios of the results for the variations in burnup, enrichment and power level to the reference case value, all at time of discharge.

Nuclide	JNFL	Bu28	Bu33	Bu45	Bu55	En3.0	En3.5	En4.0	En4.5	Po23	Po27	Po38	Po46
H3	3.59E+13	0.67	0.78	1.00	1.20	1.08	1.06	1.03	1.00	0.96	0.98	1.00	1.01
Be10	2.03E+05	0.55	0.66	1.00	1.33	1.17	1.10	1.05	1.00	1.00	1.00	1.00	1.00
C14	1.92E+10	0.69	0.84	1.00	1.31	1.32	1.20	1.10	1.00	1.00	1.00	1.00	1.00
Cl36	3.83E+08	0.71	0.86	1.00	1.29	1.30	1.19	1.09	1.00	1.00	1.00	1.00	1.00
Ca41	4.74E+06	0.70	0.85	1.00	1.31	1.32	1.20	1.10	1.00	1.00	1.00	1.00	1.00
Fe55	3.20E+11	0.76	0.89	1.00	1.24	1.30	1.20	1.09	1.00	0.83	0.89	1.00	1.06
Co60	5.78E+12	0.70	0.83	1.00	1.23	1.27	1.18	1.09	1.00	0.90	0.94	1.00	1.03
Ni59	3.53E+08	0.72	0.87	1.00	1.26	1.27	1.17	1.08	1.00	1.00	1.00	1.00	1.00
Ni63	5.04E+10	0.71	0.86	1.00	1.30	1.30	1.19	1.09	1.00	0.99	1.00	1.00	1.00
Se79	1.22E+09	0.64	0.75	1.00	1.20	0.97	0.98	0.99	1.00	1.00	1.00	1.00	1.00
Kr85	4.81E+14	0.70	0.80	1.00	1.14	0.88	0.93	0.96	1.00	0.94	0.96	1.00	1.02
Rb87	1.10E+06	0.68	0.78	1.00	1.16	0.86	0.91	0.96	1.00	1.00	1.00	1.00	1.00
Sr90	3.88E+15	0.69	0.79	1.00	1.14	0.86	0.91	0.96	1.00	0.98	0.98	1.00	1.01
Zr93	9.52E+10	0.66	0.77	1.00	1.18	0.91	0.94	0.97	1.00	1.00	1.00	1.00	1.00
Nb93M	6.47E+09	0.41	0.56	1.00	1.44	0.94	0.96	0.98	1.00	1.55	1.33	1.00	0.83
Nb94	6.39E+06	0.49	0.63	1.00	1.34	1.32	1.21	1.10	1.00	1.00	1.00	1.00	1.00
Mo93	2.13E+07	0.59	0.72	1.00	1.31	1.32	1.20	1.10	1.00	1.00	1.00	1.00	1.00
Tc99	6.63E+11	0.66	0.76	1.00	1.17	0.97	0.98	0.99	1.00	1.00	1.00	1.00	1.00
Ru106	2.29E+16	0.58	0.70	1.00	1.26	1.34	1.22	1.11	1.00	0.74	0.82	1.00	1.11
Pd107	5.04E+09	0.45	0.59	1.00	1.42	1.41	1.26	1.12	1.00	1.00	1.00	1.00	1.00
Ag108M	1.37E+08	0.66	0.79	1.00	1.28	1.29	1.18	1.09	1.00	1.00	1.00	1.00	1.00
Cd113M	2.52E+12	0.47	0.60	1.00	1.44	1.41	1.25	1.12	1.00	0.96	0.98	1.00	1.01
Sn121M	8.77E+09	0.54	0.66	1.00	1.31	1.22	1.14	1.07	1.00	0.99	0.99	1.00	1.00

Table F.3: (cont.)

Nuclide	JNFL	Bu28	Bu33	Bu45	Bu55	En3.0	En3.5	En4.0	En4.5	Po23	Po27	Po38	Po46
Sn126	1.53E+10	0.56	0.68	1.00	1.29	1.18	1.11	1.05	1.00	1.00	1.00	1.00	1.00
Sb125	6.23E+14	0.61	0.73	1.00	1.22	1.21	1.13	1.06	1.00	0.83	0.90	1.00	1.06
I129	1.52E+09	0.59	0.71	1.00	1.24	1.09	1.06	1.03	1.00	1.00	1.00	1.00	1.00
Cs134	8.68E+15	0.41	0.56	1.00	1.45	1.19	1.13	1.07	1.00	0.86	0.91	1.00	1.05
Cs135	2.50E+10	0.54	0.62	1.00	1.20	0.85	0.90	0.95	1.00	1.32	1.21	1.00	0.88
Cs137	5.18E+15	0.63	0.74	1.00	1.21	1.00	1.00	1.00	1.00	0.98	0.99	1.00	1.01
Pm147	5.67E+15	1.02	1.02	1.00	0.91	0.82	0.87	0.93	1.00	0.88	0.93	1.00	1.04
Sm147	7.44E+04	0.59	0.72	1.00	1.12	0.78	0.85	0.93	1.00	1.46	1.29	1.00	0.84
Sm151	2.00E+13	0.67	0.71	1.00	1.09	0.98	0.98	0.99	1.00	0.97	0.98	1.00	1.01
Eu152	4.11E+11	0.65	0.68	1.00	0.98	0.78	0.83	0.91	1.00	1.52	1.32	1.00	0.84
Eu154	4.71E+14	0.37	0.53	1.00	1.49	1.28	1.18	1.09	1.00	0.97	0.98	1.00	1.01
Eu155	3.36E+14	0.38	0.52	1.00	1.49	1.30	1.20	1.10	1.00	0.96	0.98	1.00	1.01
Ho166M	1.02E+08	0.20	0.36	1.00	2.34	2.37	1.77	1.33	1.00	1.00	1.00	1.00	1.00
Pb210	1.92E+02	0.27	0.40	1.00	1.93	1.11	1.08	1.04	1.00	2.12	1.58	1.00	0.79
Po210	1.35E+09	0.85	0.92	1.00	1.14	1.25	1.17	1.08	1.00	0.65	0.76	1.00	1.19
Ra226	1.42E+03	0.46	0.61	1.00	1.32	0.58	0.71	0.85	1.00	2.58	1.86	1.00	0.67
Ra228	1.84E-01	0.29	0.45	1.00	1.64	0.81	0.89	0.95	1.00	2.44	1.79	1.00	0.68
Ac227	3.19E+04	0.35	0.50	1.00	1.40	0.63	0.76	0.88	1.00	2.54	1.84	1.00	0.67
Th228	1.61E+08	0.37	0.49	1.00	1.69	0.96	0.98	1.00	1.00	1.98	1.56	1.00	0.75
Th229	1.08E+04	0.31	0.45	1.00	1.88	1.08	1.07	1.04	1.00	1.82	1.48	1.00	0.78
Th230	1.69E+06	0.81	0.89	1.00	1.01	0.55	0.69	0.84	1.00	1.61	1.37	1.00	0.82
Th232	1.41E+00	0.46	0.61	1.00	1.34	0.78	0.86	0.94	1.00	1.61	1.37	1.00	0.82
Pa231	1.00E+06	0.54	0.67	1.00	1.20	0.63	0.76	0.88	1.00	1.61	1.37	1.00	0.82

Table F.3: (cont.)

Nuclide	**JNFL**	**Bu28**	**Bu33**	**Bu45**	**Bu55**	**En3.0**	**En3.5**	**En4.0**	**En4.5**	**Po23**	**Po27**	**Po38**	**Po46**
U232	6.57E+08	0.36	0.49	1.00	1.62	0.99	1.01	1.01	1.00	1.47	1.29	1.00	0.85
U233	7.74E+05	0.75	0.80	1.00	1.01	0.67	0.78	0.89	1.00	1.06	1.04	1.00	0.98
U234	5.97E+10	1.28	1.20	1.00	0.84	0.56	0.70	0.84	1.00	1.00	1.00	1.00	1.00
U235	7.21E+08	2.07	1.70	1.00	0.60	0.40	0.56	0.76	1.00	1.00	1.00	1.00	1.00
U236	1.44E+10	0.79	0.87	1.00	1.04	0.70	0.81	0.91	1.00	1.00	1.00	1.00	1.00
U238	1.15E+10	1.01	1.01	1.00	0.99	1.01	1.01	1.00	1.00	1.00	1.00	1.00	1.00
Np237	1.81E+10	0.48	0.62	1.00	1.30	0.93	0.98	1.00	1.00	1.01	1.01	1.00	1.00
Pu238	1.46E+14	0.27	0.43	1.00	1.66	1.23	1.17	1.09	1.00	1.07	1.05	1.00	0.98
Pu239	1.14E+13	0.93	0.97	1.00	1.00	1.01	1.01	1.01	1.00	1.00	1.00	1.00	1.00
Pu240	2.12E+13	0.65	0.78	1.00	1.09	1.10	1.07	1.04	1.00	1.00	1.00	1.00	1.00
Pu241	5.25E+15	0.53	0.67	1.00	1.19	1.19	1.14	1.07	1.00	0.99	0.99	1.00	1.00
Pu242	8.20E+10	0.29	0.45	1.00	1.60	1.63	1.41	1.19	1.00	1.00	1.00	1.00	1.00
Am241	4.61E+12	0.45	0.62	1.00	1.22	1.11	1.08	1.04	1.00	1.58	1.35	1.00	0.82
Am242M	3.99E+11	0.32	0.47	1.00	1.28	1.16	1.11	1.06	1.00	1.58	1.35	1.00	0.82
Am243	8.85E+11	0.16	0.30	1.00	2.05	2.15	1.69	1.31	1.00	1.00	1.00	1.00	1.00
Cm244	1.15E+14	0.08	0.20	1.00	2.81	3.03	2.12	1.46	1.00	0.99	0.99	1.00	1.01
Cm245	1.10E+10	0.05	0.13	1.00	3.35	3.66	2.41	1.56	1.00	0.99	1.00	1.00	1.01
Cm246	1.99E+09	0.03	0.11	1.00	4.67	5.19	3.04	1.75	1.00	0.99	0.99	1.00	1.00
Total	5.39E+16	0.60	0.72	1.00	1.24	1.18	1.12	1.06	1.00	0.84	0.90	1.00	1.06
Alpha	3.00E+14	0.25	0.39	1.00	2.03	1.91	1.52	1.23	1.00	1.04	1.02	1.00	0.99
Beta/Gamma	5.36E+16	0.60	0.72	1.00	1.24	1.17	1.11	1.06	1.00	0.84	0.90	1.00	1.06

Table F.4: Nuclide activities ($Bq(t_{IHM})^{-1}$) calculated with BOXER for reference case 1 (JNFL) from Table 2 and the ratios of the results for the variations in burnup, enrichment and power level to the reference case value, all at time of discharge.

Nuclide	JNFL	Bu28	Bu33	Bu45	Bu55	En3.0	En3.5	En4.0	En4.5	Po23	Po27	Po38	Po46
H3	3.90E+13	0.64	0.74	1.00	1.21	1.08	1.05	1.03	1.00	0.99	1.00	1.00	1.00
Be10	1.04E+07	0.61	0.72	1.00	1.22	1.03	1.02	1.01	1.00	1.00	1.00	1.00	1.00
C14	3.46E+10	0.58	0.69	1.00	1.29	1.33	1.20	1.09	1.00	1.00	1.00	1.00	1.00
Cl36	4.82E+08	0.58	0.70	1.00	1.28	1.44	1.27	1.12	1.00	1.00	1.00	1.00	1.00
Ca41	6.53E+06	0.57	0.69	1.00	1.30	1.46	1.27	1.12	1.00	1.00	1.00	1.00	1.00
Fe55	5.15E+11	0.65	0.75	1.00	1.21	1.37	1.22	1.10	1.00	0.83	0.89	1.00	1.06
Co60	4.95E+12	0.63	0.74	1.00	1.22	1.30	1.18	1.08	1.00	0.89	0.94	1.00	1.03
Ni59	4.64E+08	0.61	0.72	1.00	1.24	1.39	1.24	1.11	1.00	1.00	1.00	1.00	1.00
Ni63	6.16E+10	0.58	0.70	1.00	1.28	1.45	1.27	1.12	1.00	1.00	1.00	1.00	1.00
Se79	9.94E+08	0.64	0.75	1.00	1.20	0.96	0.98	0.99	1.00	1.00	1.00	1.00	1.00
Kr85	2.23E+15	0.70	0.80	1.00	1.13	0.89	0.93	0.97	1.00	0.94	0.96	1.00	1.02
Rb87	1.04E+06	0.68	0.78	1.00	1.17	0.89	0.93	0.97	1.00	1.01	1.01	1.00	1.00
Sr90	3.79E+15	0.69	0.79	1.00	1.15	0.88	0.93	0.97	1.00	0.98	0.99	1.00	1.01
Zr93	9.13E+10	0.66	0.76	1.00	1.18	0.93	0.96	0.98	1.00	1.00	1.00	1.00	1.00
Nb93M	6.12E+09	0.41	0.56	1.00	1.44	0.95	0.97	0.99	1.00	1.56	1.34	1.00	0.83
Nb94	1.25E+07	0.54	0.67	1.00	1.30	1.16	1.10	1.05	1.00	0.75	0.82	1.00	1.14
Mo93	8.41E+07	0.58	0.70	1.00	1.27	1.11	1.07	1.03	1.00	1.00	1.00	1.00	1.00
Tc99	6.55E+11	0.67	0.77	1.00	1.17	0.96	0.98	0.99	1.00	1.00	1.00	1.00	1.00
Ru106	2.35E+16	0.61	0.72	1.00	1.22	1.28	1.17	1.08	1.00	0.72	0.82	1.00	1.12
Pd107	5.20E+09	0.47	0.61	1.00	1.38	1.32	1.20	1.09	1.00	1.00	1.00	1.00	1.00
Ag108M	9.07E+07	0.55	0.67	1.00	1.32	1.31	1.19	1.08	1.00	1.00	1.00	1.00	1.00
Cd113M	3.58E+12	0.51	0.64	1.00	1.34	1.26	1.16	1.07	1.00	0.96	0.97	1.00	1.01
Sn121M	1.23E+11	0.49	0.63	1.00	1.34	1.28	1.17	1.08	1.00	0.98	0.99	1.00	1.00

Table F.4: (cont.)

Nuclide	JNFL	Bu28	Bu33	Bu45	Bu55	En3.0	En3.5	En4.0	En4.5	Po23	Po27	Po38	Po46
Sn126	1.62E+10	0.51	0.65	1.00	1.33	1.22	1.14	1.06	1.00	0.99	1.00	1.00	1.00
Sb125	6.38E+14	0.55	0.68	1.00	1.27	1.26	1.16	1.07	1.00	0.85	0.90	1.00	1.05
I129	1.53E+09	0.60	0.72	1.00	1.25	1.06	1.04	1.02	1.00	1.00	1.00	1.00	1.01
Cs134	8.69E+15	0.43	0.58	1.00	1.39	1.14	1.09	1.04	1.00	0.86	0.91	1.00	1.05
Cs135	2.34E+10	0.65	0.75	1.00	1.20	0.76	0.84	0.91	1.00	1.32	1.21	1.00	0.88
Cs137	5.22E+15	0.63	0.74	1.00	1.21	1.00	1.00	1.00	1.00	0.98	0.99	1.00	1.01
Pm147	7.17E+15	0.93	0.97	1.00	0.98	0.86	0.91	0.96	1.00	0.87	0.92	1.00	1.05
Sm147	8.20E+04	0.58	0.71	1.00	1.17	0.85	0.90	0.95	1.00	1.45	1.28	1.00	0.84
Sm151	1.63E+13	0.85	0.90	1.00	1.07	0.83	0.88	0.94	1.00	0.95	0.97	1.00	1.02
Eu152	2.99E+11	0.82	0.90	1.00	1.02	0.63	0.74	0.87	1.00	1.51	1.31	1.00	0.86
Eu154	5.10E+14	0.38	0.54	1.00	1.43	1.21	1.13	1.06	1.00	0.97	0.98	1.00	1.01
Eu155	2.05E+14	0.46	0.60	1.00	1.39	1.16	1.07	1.03	1.00	0.96	0.98	1.00	1.03
Ho166M	2.41E+08	0.17	0.31	1.00	2.17	2.17	1.65	1.27	1.00	0.98	0.99	1.00	1.01
Pb210	7.90E+03	0.28	0.44	1.00	1.66	0.75	0.84	0.92	1.00	1.63	1.38	1.00	0.81
Po210	3.53E+09	0.85	0.90	1.00	1.09	1.20	1.12	1.06	1.00	0.64	0.75	1.00	1.20
Ra226	1.41E+03	0.46	0.61	1.00	1.34	0.61	0.74	0.87	1.00	2.58	1.86	1.00	0.67
Ra228	1.78E-01	0.30	0.46	1.00	1.62	0.81	0.88	0.94	1.00	2.43	1.79	1.00	0.68
Ac227	2.96E+04	0.41	0.57	1.00	1.32	0.53	0.68	0.84	1.00	2.54	1.84	1.00	0.68
Th228	1.35E+08	0.41	0.53	1.00	1.61	0.83	0.90	0.95	1.00	1.93	1.53	1.00	0.76
Th229	5.21E+03	0.34	0.48	1.00	1.72	1.02	1.02	1.01	1.00	1.71	1.42	1.00	0.80
Th230	1.56E+06	0.83	0.90	1.00	1.02	0.58	0.71	0.85	1.00	1.62	1.37	1.00	0.82
Th232	1.35E+00	0.47	0.61	1.00	1.34	0.79	0.87	0.93	1.00	1.61	1.36	1.00	0.81
Pa231	1.11E+06	0.56	0.69	1.00	1.19	0.61	0.74	0.87	1.00	1.59	1.35	1.00	0.82

Table F.4: (cont.)

Nuclide	JNFL	Bu28	Bu33	Bu45	Bu55	En3.0	En3.5	En4.0	En4.5	Po23	Po27	Po38	Po46
U232	4.34E+08	0.41	0.54	1.00	1.52	0.82	0.89	0.95	1.00	1.50	1.30	1.00	0.85
U233	1.14E+06	0.86	0.92	1.00	0.99	0.57	0.70	0.85	1.00	1.05	1.03	1.00	0.99
U234	5.41E+10	1.31	1.22	1.00	0.84	0.56	0.70	0.85	1.00	1.01	1.00	1.00	1.00
U235	8.82E+08	1.84	1.55	1.00	0.66	0.35	0.53	0.75	1.00	1.00	1.00	1.00	1.00
U236	1.37E+10	0.80	0.88	1.00	1.04	0.71	0.82	0.91	1.00	1.00	1.00	1.00	0.99
U238	1.15E+10	1.02	1.01	1.00	0.99	1.01	1.01	1.01	1.00	1.00	1.00	1.00	1.00
Np237	2.15E+10	0.52	0.66	1.00	1.26	0.85	0.91	0.96	1.00	1.00	1.00	1.00	1.00
Pu238	1.91E+14	0.30	0.46	1.00	1.59	1.05	1.04	1.03	1.00	1.06	1.04	1.00	0.98
Pu239	1.37E+13	0.94	0.98	1.00	0.99	0.87	0.91	0.96	1.00	1.00	1.00	1.00	1.01
Pu240	2.10E+13	0.62	0.75	1.00	1.16	1.11	1.08	1.04	1.00	1.01	1.00	1.00	1.00
Pu241	5.95E+15	0.61	0.75	1.00	1.13	0.99	1.00	1.01	1.00	0.98	0.98	1.00	1.01
Pu242	8.80E+10	0.32	0.49	1.00	1.51	1.52	1.32	1.15	1.00	0.99	0.99	1.00	1.01
Am241	6.33E+12	0.46	0.63	1.00	1.19	0.86	0.92	0.96	1.00	1.56	1.34	1.00	0.83
Am242M	4.22E+11	0.43	0.61	1.00	1.19	0.81	0.89	0.97	1.00	1.54	1.32	1.00	0.83
Am243	9.61E+11	0.19	0.34	1.00	1.86	1.79	1.47	1.21	1.00	0.99	0.99	1.00	1.01
Cm244	1.32E+14	0.10	0.23	1.00	2.46	2.29	1.71	1.30	1.00	0.97	0.98	1.00	1.02
Cm245	1.49E+10	0.07	0.18	1.00	2.79	2.31	1.72	1.31	1.00	0.96	0.97	1.00	1.02
Cm246	2.51E+09	0.03	0.11	1.00	3.98	3.71	2.35	1.51	1.00	0.97	0.98	1.00	1.02
Total	5.83E+16	0.63	0.74	1.00	1.20	1.11	1.07	1.03	1.00	0.84	0.90	1.00	1.07
Alpha	3.66E+14	0.28	0.42	1.00	1.84	1.49	1.28	1.12	1.00	1.03	1.02	1.00	0.99
Beta/Gamma	5.80E+16	0.63	0.74	1.00	1.20	1.11	1.07	1.03	1.00	0.84	0.89	1.00	1.06