SKBF TEKNISK
KBS RAPPORT

83-12

Calculation of activity content and related properties in PWR and BWR fuel using ORIGEN 2

Ove Edlund

Studsvik Energiteknik AB, Nyköping, Sweden 1983-03-07

SVENSK KÄRNBRÄNSLEFÖRSÖRJNING AB / AVDELNING KBS

POSTADRESS: Box 5864, 102 48 Stockholm, Telefon 08-67 95 40

CALCULATION OF ACTIVITY CONTENT AND RELATED PROPERTIES IN PWR AND BWR FUEL USING ORIGEN 2

Ove Edlund

Studsvik Energiteknik AB
Nyköping, Sweden 1983-03-07

This report concerns a study which was conducted for SKBF/KBS. The conslusions and viewpoints presented in the report are those of the author(s) and do not necessarily coincide with those of the client.

A list of other reports published in this series during 1983 is attached at the end of this report. Information on KBS technical reports from 1977-1978 (TR 121), 1979 (TR 79-28), 1980 (TR 80-26) and 1981 (TR 81-17) is available through SKBF/KBS.

Studsvik Arbetsrapport - Technical Report

83-03-07 NW-82/191

Calculation of activity content and related properties in PWR and BWR fuel using ORIGEN 2

Ove Edlund

PN5222A

SUMMARY

This report lists (in Table 1) the conditions for calculations of the core inventory for a PWR and BWR. The calculations have been performed using the computer code ORIGEN 2. The amount (grams), the total radioactivity (bequerels), the thermal power (watts), the radioactivity from the α-decay (bequerels), and the neutron emission (neutrons/sec) from the core after the last burnup have been determined.

All the parameters have been calculated as a function of the burnup and the natural decay, the latter over a time period of 0 - 1.0E07 years. The calculations have been performed for 68 heavy nuclides, 60 daughter nuclides, to the heavy nuclides with atomic numbers under 92, 852 fission products and 7 light nuclides.

The most important results are listed in Tables 4 - 11, which also are the basis of Figures 1 - 8.

Tables 2 - 3 contain the activity (bequerels), per unit mass of nuclear fuel, of the most important nuclides as a function of the decay time for the PWR and BWR conditions considered.

1 INTRODUCTION

At the request of SKBF/KBS the values of different parameters (see chapter 3) have been calculated for a core inventory normalized to a unit mass (1 ton) of nuclear fuel for a PWR and a BWR. The Ringhals 3 reactor has been considered as the reference for the PWR, and the Forsmark 1 reactor is the reference for the BWR type.

2 CALCULATION CONDITIONS

Four different cases have been studied for each type of reactor (see Tables 1a and 1b). Furthermore, the values of the parameters in the spent fuel have been investigated as a function of time after the removal of fuel from the reactor and for the subsequent 10^7 years.

All calculations have been performed by the most recent updated version of the American computer code ORIGEN 2 /1 -4/ for 60 daughter nuclides to the heavy nuclides with atomic numbers under 92, 68 heavy nuclides, 852 fission products and 7 light nuclides. In Table 1 the input variables for the calculations are listed.

Table 1 a The input parameter values for the PWR

Specific power	38.5 W/G	38.5 W/G	38.5 W/G	38.5 W/G
Total burnup	33 GWD/TU	38 GWD/TU	38 GWD/TU	45 GWD/TU
Enrichment U-235	3.2 %	3.2 %	3.6 %	3.2 %
U-234	0.029 %	0.029 %	0.032 % *)	0.029 %
U-238	96.771 %	96.771 %	96.368 %	96.771 %
Burnup 1	285.71 d	246.75 d	246.75 d	246.75 d
Decay 1	79.53 d	118.49 d	118.49 d	118.49 d
Burnup 2	285.71 d	246.75 d	246.75 d	246.75 d
Decay 2	79.53 d	118.49 d	118.49 d	118.49 d
Burnup 3	285.71 d	246.75 d	246.75 d	246.75 d
Decay 3	-	118.49 d	118.49 d	118.49 d
Burnup 4	-	246.75 d	246.75 d	246.75 d
Decay 4	-	-	-	118.49 d
Burnup 5	-	-	-	181.82 d

Table 1 b The input parameter values for the BWR

Specific power	22.0 W/G	22.0 W/G	22.0 W/G	22.0 W/G
Total burnup	28 GWD/TU	33 GWD/TU	38 GWD/TU	38 GWD/TU
Enrichment U-235	2.8 %	2.8 %	2.8 %	3.2 %
U-234	0.0254 %	0.0254 %	0.0254 %	0.029 % *)
U-238	97.175 %	97.175 %	97.175 %	96.771 %
Burnup 1	318.18 d	300.00 d	300.00 d	300.00 d
Decay 1	47.06 d	65.24 d	65.24 d	65.24 d
Burnup 2	318.18 d	300.00 d	300.00 d	300.00 d
Decay 2	47.06 d	65.24 d	65.24 d	65.24 d
Burnup 3	318.18 d	300.00 d	300.00 d	300.00 d
Decay 3	47.06 d	65.24 d	65.24 d	65.24 d
Burnup 4	318.18 d	300.00 d	300.00 d	300.00 d
Decay 4	-	65.24 d	65.24 d	65.24 d
Burnup 5	-	300.00 d	300.00 d	300.00 d
Decay 5	-	-	65.24 d	65.24 d
Burnup 6	-	-	227.27 d	227.27 d

*) This figure has been obtained by a proportional increase of U-234 in relation to the increase of U-235, based on the natural abundance of both the nuclides, 0.0055 % (U-234) and 0.72 % (U-235)

The decay time steps (years) after the last burnup were taken to be:
1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 35, 40, 60, 100, 300, 1 000, 3 000, 10 000, 30 000, 100 000, 300 000, 10^6, 10^7.

3 RESULTS

The results have been given in groups separated into nuclides and elements, and also as the sum of the different groups. All results are reported in data lists.

The most important parameters regarding the waste in this report have been considered as follows.

1) The radioactivity expressed in bequerels/TU of the most important nuclides for the BWR and PWR conditions considered.
PWR: Tables 2a, 2b
BWR: Tables 3a, 3b.

2) The total radioactivity expressed in bequerels.
PWR: Table 4, Figure 1
BWR: Table 8, Figure 5

3) The contribution to the radioactivity from the α-decay expressed in bequerels.
PWR: Table 5, Figure 2
BWR: Table 9, Figure 6.

4) The thermal power expressed in watts.
PWR: Table 6, Figure 3
BWR: Table 10, Figure 7

5) The total neutron emission expressed in neutrons/sec.
PWR: Table 7, Figure 4
BWR: Table 11, Figure 8.

4 FURTHER INFORMATION

Besides the results in this report other results obtainable from the complete data lists mentioned above are worth describing.

a) The concentration in grams is given for all nuclides.

b) The photon emission after the last burnup is described in 18 energy groups /2/.

c) Other nuclide specific data can be taken from reference /2/.

d) The neutron emission mentioned above refers to two kinds of emission, namely spontaneous fission and (α, n) reactions.

5 DISCUSSION

Burnup

The inventory of a specific fission product in a core can be shown to be proportional to the expression

$$(1 - e^{-\lambda T}) \cdot e^{-\lambda t}$$

where λ is the decay constant of the nuclide, T is the burnup time, and t is the total time including time for service etc. The nuclides of interest here have a half-life considerably higher than the burnup time T, which means that λT is very small, and also λt ($e^{-\lambda t} \sim 1$).

$$\because \ 1 - e^{-\lambda T} = 1 - 1 + \lambda T - \frac{(\lambda T)^2}{2!} \simeq \lambda T$$

$\because$ The activity is directly proportional to λT, which is confirmed in Figure 10 (BWR).

In the case of a PWR (Figure 9) the fission product behaviour is not the same. It seems that the activity for most of the nuclides, except Tc 99, at higher burnup increases more quickly than is to be expected from a linear relationship with T. One of the explanations to this discrepancy could be that a different neutron cross section library was used for the 45 Gwd/TU case, because the cross section is dependent on the burnup. The inventory of fissionable transuraniums is therefore different for that case, and since the peaks of the fission yield curves for these transuraniums are located at different mass numbers the inventory can have an influence on the distribution of the fission products.

The numerical values on which Figures 9 and 10 are based are listed in Table 12.

Concerning the actinides: it is more difficult to explain the shapes of the curves because there are several factors which influence their composition.

Buildup and decay

Figures 11 and 12 show the buildup and decay during storage for the most important nuclides, from a long term safety point of view. One can observe, after about 10^4 years, how Pu 241 and Am 241 follow the curve of Cm 245, which is the precursor of them. Another interesting feature is the curves within the time interval 10^5 - 10^6 years. The decay chain U 234 - Th 230 - Ra 226 with their daughters reaches its maximum here. Another decay chain is U 233 - Th 229 - Ac 225 and so on. It is known that the internal dose conversion factor (ingestion) for Np 237 /13/ is very high (see Table 13), and ought in particular to be considered in the long term. Among the fission products, Tc 99 seems to be of special interest over the same time period. Considering the timescale $>10^6$ years, Cs 135 and I 129 are still active, and U 238 and its daughters reach equilibrium successively.

The maximum values of the activity and the time interval for those values are listed in Table 13 for the most important actinides.

Uncertainty

In order to obtain information regarding the uncertainty in the calculations of the core inventory, it is necessary to refer to a comparison made using another computer code, or to measurements. It is convenient in this context to refer to the work of Etemad and Ekberg /14/.

In their report ORIGEN 2 results for some important actinides are compared to results of calculations made with the more accurate cell code CASMO /15/, for a PWR-case similar to the one studied here. In the present study, however, the ORIGEN 2 code has been used in slightly different way than by Etemad and Ekberg. The differences are:

1. Decay steps have been included in the calculations to simulate the yearly maintenance periods.

2. Shorter irradiation steps were used in the calculations by Etemad and Ekberg.

In Table 14 a comparison is made between the results of the two ORIGEN 2-calculations and the CASMO-calculation. Some differences can be seen between the two ORIGEN 2 calculations. The main cause of these are the use of different time steps in the calculations /16/. The neutron cross sections are namely burnup dependent. This is most clearly visible in the calculated amounts of Pu 240 and Pu 241, where more accurate results are obtained with the shorter time steps.

For short-lived nuclides, like Cm-242 and nuclides that are daughters to short-lived nuclides, like Am-241, the decay steps are also of importance.

From Table 14 it can be seen that the maximum difference between the ORIGEN 2 calculations presented in this report and CASMO calculations is 35 % for any particular heavy nuclide.

The accuracy of the CASMO code for the prediction of Pu and other heavy nuclides has been verified previously through comparison with the experimental data /18/.

Since the ORIGEN 2 code is an updated version of the old ORIGEN, Q-values and fission yield data are more consistent with the experimental data. The thermal power for example in this work is in general 10-15 % lower than the values obtained by the old ORIGEN /17, Table 4/.

6 REFERENCES

1 BELL M J
ORIGEN - The ORNL Isotope Generation and Depletion Code.
ORNL-4628 (May 1973)

2 CROFF A G
ORIGEN2 - A Revised and Updated Version of the Oak Ridge Isotope Generation and Depletion Code.
ORNL-5621

3 CROFF A G, BJERKE M A, MORRISON G W, PETRIE L M
Revised Uranium-Plutonium Cycle PWR and BWR Models for the ORIGEN Computer Code
ORNL/TM-6051 (Sept 1978)

4 CROFF A G, BJERKE M E
Alternative Fuel Cycle PWR Models for the ORIGEN Computer Code.
ORNL/TM-7005 (Feb 1980)

5 CROFF A G, HAESE R L, GOVE N B
Updated Decay and Photon Libraries for the ORIGEN Code.
ORNL/TM-6055 (Feb 1979)

6 STEHN J R et al
Neutron Cross Section, 2nd ed, Suppl 2.
BNL-325 (1964)

7 ENDF/B-V Library Tapes 401-411 and 414-419. Available from the National Neutron Cross Section Center.
Brookhaven National Laboratory (Dec 1974)

8 ENDF/B-V Library Tapes 521 and 522. Available from the National Neutron Cross Section Center.
Brookhaven National Laboratory (July 1979)

9 DRAKE M K
A "Compliation of Resonance Integrals"
Nucleonics 24 (8), 108-111 (Aug 1966)

10 MEEK M E, RIDER B F
Summary of Fission Product Yields for U-235, U-238, Pu-239 and Pu-241 at Thermal, Fission Spectrum, and 14 MeV Neutron Energies.
APED-5398-A (Rev) (1968)

11 KEE C W
A Revised Light Element Library for the ORIGEN Code.
ORNL/TM-4896 (May 1975)

12 LEDERER C M, HOLLANDER J M, PERLMAN S
Table of Isotopes, 6th ed.
Wiley, New York, 1967

13 ANNALS OF THE ICRP Vol 5, No 1-6 (1981)
ICRP Publ no 30
Supplement to Part 2
Limits for Intakes of Radionuclides by Workers.

14 ETEMAD M A, EKBERG K
A Study of heavy nuclide contents calculated by ORIGEN 2 and CASMO computer code.
STUDSVIK/NR-81/35, (1981).

15 AHLIN Å, EDENIUS M and HÄGGBLOM H
The fuel assembly burnup program, CASMO
AE-RF-76-4158 (1977).
STUDSVIK ENERGITEKNIK AB.

16 Personal communication

17 EKBERG K, KJELLBERT N, OLSSON G
Resteffektstudier för KBS.
KBS Teknisk rapport nr 7.
Kärnbränslesäkerhet, Fack,
S-102 40 Stockholm. Sweden.

18 AHLIN Å and EDENIUS M
"The collision probability module EPRI-CPM" developed for the Electric Power Research Institute as part of the Advanced Recycle Methodology Package.

TABLE 2A. FISSIONPRODUCTS IN PWR-FUEL.
38 GWD/TONU(3.2%) BQ/TONU.

NUCLIDE	40Y	100Y	1 000Y	10 000Y	100 000Y	1MY	10MY
H 3	2.5E+12	8.5E+10	9.6E-12	0.	0.	0.	0.
BE 10	1.2E+05	1.2E+05	1.2E+05	1.2E+05	1.2E+05	8.1E+04	1.6E+03
C 14	4.8E+06	4.8E+06	4.4E+06	1.5E+06	2.8E+01	0.	0.
SE 79	1.7E+10	1.7E+10	1.7E+10	1.6E+10	5.9E+09	4.1E+05	0.
KR 81	2.1E+04	2.1E+04	2.1E+04	2.1E+04	1.6E+04	7.8E+02	9.6E-11
KR 85	2.8E+13	5.9E+11	3.1E-14	0.	0.	0.	0.
RB 87	8.9E+05	8.9E+05	8.9E+05	8.9E+05	8.9E+05	8.9E+05	8.9E+05
SR 90	1.1E+15	2.7E+14	1.3E+05	0.	0.	0.	0.
Y 90	1.1E+15	2.7E+14	1.3E+05	0.	0.	0.	0.
ZR 93	7.4E+10	7.4E+10	7.4E+10	7.4E+10	7.0E+10	4.8E+10	8.1E+08
NB 93M	6.3E+10	7.0E+10	7.0E+10	7.0E+10	6.7E+10	4.4E+10	7.8E+08
NB 94	6.3E+06	6.3E+06	5.9E+06	4.4E+06	2.0E+05	9.3E-09	0.
TC 99	5.6E+11	5.6E+11	5.6E+11	5.2E+11	4.1E+11	2.1E+10	4.1E-03
PD107	5.2E+09	5.2E+09	5.2E+09	5.2E+09	5.2E+09	4.8E+09	1.9E+09
AG108	1.0E+05	7.0E+04	5.2E+02	2.5E-19	0.	0.	0.
AG108M	1.1E+06	8.1E+05	5.9E+03	2.8E-18	0.	0.	0.
CD113M	4.1E+11	2.3E+10	5.9E-09	0.	0.	0.	0.
IN115	5.6E-01	5.6E-01	5.6E-01	5.6E-01	5.6E-01	5.6E-01	5.6E-01
SN121M	5.2E+09	2.3E+09	8.5E+03	0.	0.	0.	0.
TE123	1.2E-01	1.2E-01	1.2E-01	1.2E-01	1.2E-01	1.2E-01	1.2E-01
SB125	2.6E+10	7.8E+03	0.	0.	0.	0.	0.
TE125M	6.3E+09	1.9E+03	0.	0.	0.	0.	0.
SN126	3.4E+10	3.4E+10	3.4E+10	3.1E+10	1.7E+10	3.3E+07	0.
SB126	4.8E+09	4.8E+09	4.8E+09	4.4E+09	2.4E+09	4.4E+06	0.
SB126M	3.4E+10	3.4E+10	3.4E+10	3.1E+10	1.7E+10	3.3E+07	0.
I129	1.3E+09	1.3E+09	1.3E+09	1.3E+09	1.3E+09	1.3E+09	8.5E+08
CS134	1.0E+10	1.7E+01	0.	0.	0.	0.	0.
CS135	1.4E+10	1.4E+10	1.4E+10	1.4E+10	1.4E+10	1.1E+10	7.0E+08
CS137	1.7E+15	4.4E+14	4.1E+05	0.	0.	0.	0.
BA137M	1.6E+15	4.1E+14	3.7E+05	0.	0.	0.	0.
LA138	4.1E+00	4.1E+00	4.1E+00	4.1E+00	4.1E+00	4.1E+00	4.1E+00
CE142	1.1E+06	1.1E+06	1.1E+06	1.1E+06	1.1E+06	1.1E+06	1.1E+06
ND144	6.7E+01	6.7E+01	6.7E+01	6.7E+01	6.7E+01	6.7E+01	6.7E+01
PM147	1.2E+11	1.6E+04	0.	0.	0.	0.	0.
SM147	1.9E+05	1.9E+05	1.9E+05	1.9E+05	1.9E+05	1.9E+05	1.9E+05
SM148	2.3E+00	2.3E+00	2.3E+00	2.3E+00	2.3E+00	2.3E+00	2.3E+00
SM149	3.3E-02	3.3E-02	3.3E-02	3.3E-02	3.3E-02	3.3E-02	3.3E-02
SM151	1.0E+13	6.7E+12	6.3E+09	0.	0.	0.	0.
EU152	3.4E+10	1.6E+09	1.9E-11	0.	0.	0.	0.
GD152	2.0E-02	2.1E-02	2.1E-02	2.1E-02	2.1E-02	2.1E-02	2.1E-02
EU154	2.0E+13	1.6E+11	0.	0.	0.	0.	0.
EU155	1.1E+12	2.6E+08	0.	0.	0.	0.	0.
HO166M	1.5E+08	1.4E+08	8.5E+07	4.8E+05	1.3E-17	0.	0.
TM171	2.9E+01	1.1E-08	0.	0.	0.	0.	0.

TABLE 2B. CONTENT OF HEAVY NUCLIDES IN PWR-FUEL
38 GWD/TONU (3.2%) BQ/TONU.

NUCLIDE	40Y	100Y	1 000Y	10 000Y	100 000Y	1MY	10MY
TL207	7.0E+05	1.4E+06	1.1E+07	1.1E+08	7.0E+08	8.9E+08	8.9E+08
TL208	2.8E+08	1.6E+08	4.1E+04	1.5E+04	3.1E+04	2.4E+05	2.1E+06
TL209	3.0E+02	9.3E+02	1.3E+05	1.7E+07	4.1E+08	9.6E+08	4.8E+07
PB209	1.4E+04	4.4E+04	5.9E+06	8.1E+08	1.8E+10	4.4E+10	2.3E+09
PB210	5.2E+04	5.6E+05	1.3E+08	5.9E+09	4.4E+10	1.8E+10	1.2E+10
PB211	7.0E+05	1.4E+06	1.1E+07	1.1E+08	7.0E+08	8.9E+08	8.9E+08
PB212	7.8E+08	4.4E+08	1.1E+05	4.1E+04	8.5E+04	6.7E+05	5.9E+06
PB214	1.6E+05	1.0E+06	1.3E+08	5.9E+09	4.4E+10	1.8E+10	1.2E+10
BI210	5.2E+04	5.6E+05	1.3E+08	5.9E+09	4.4E+10	1.8E+10	1.2E+10
BI211	7.0E+05	1.4E+06	1.1E+07	1.1E+08	7.0E+08	8.9E+08	8.9E+08
BI212	7.8E+08	4.4E+08	1.1E+05	4.1E+04	8.5E+04	6.7E+05	5.9E+06
BI213	1.4E+04	4.4E+04	5.9E+06	8.1E+08	1.8E+10	4.4E+10	2.3E+09
BI214	1.6E+05	1.0E+06	1.3E+08	5.9E+09	4.4E+10	1.8E+10	1.2E+10
PO210	5.2E+04	5.6E+05	1.3E+08	5.9E+09	4.4E+10	1.8E+10	1.2E+10
PO211	2.0E+03	4.1E+03	3.3E+04	3.0E+05	2.0E+06	2.5E+06	2.5E+06
PO212	5.2E+08	2.8E+08	7.4E+04	2.7E+04	5.6E+04	4.4E+05	3.7E+06
PO213	1.4E+04	4.1E+04	5.9E+06	7.8E+08	1.8E+10	4.4E+10	2.2E+09
PO214	1.6E+05	1.0E+06	1.3E+08	5.9E+09	4.4E+10	1.8E+10	1.2E+10
PO215	7.0E+05	1.4E+06	1.1E+07	1.1E+08	7.0E+08	8.9E+08	8.9E+08
PO216	7.8E+08	4.4E+08	1.1E+05	4.1E+04	8.5E+04	6.7E+05	5.9E+06
PO218	1.6E+05	1.0E+06	1.3E+08	5.9E+09	4.4E+10	1.8E+10	1.2E+10
AT217	1.4E+04	4.4E+04	5.9E+06	8.1E+08	1.8E+10	4.4E+10	2.3E+09
RN219	7.0E+05	1.4E+06	1.1E+07	1.1E+08	7.0E+08	8.9E+08	8.9E+08
RN220	7.8E+08	4.4E+08	1.1E+05	4.1E+04	8.5E+04	6.7E+05	5.9E+06
RN222	1.6E+05	1.0E+06	1.3E+08	5.9E+09	4.4E+10	1.8E+10	1.2E+10
FR221	1.4E+04	4.4E+04	5.9E+06	8.1E+08	1.8E+10	4.4E+10	2.3E+09
FR223	9.6E+03	2.0E+04	1.6E+05	1.5E+06	1.0E+07	1.2E+07	1.2E+07
RA223	7.0E+05	1.4E+06	1.1E+07	1.1E+08	7.0E+08	8.9E+08	8.9E+08
RA224	7.8E+08	4.4E+08	1.1E+05	4.1E+04	8.5E+04	6.7E+05	5.9E+06
RA225	1.4E+04	4.4E+04	5.9E+06	8.1E+08	1.8E+10	4.4E+10	2.3E+09
RA226	1.6E+05	1.0E+06	1.3E+08	5.9E+09	4.4E+10	1.8E+10	1.2E+10
RA228	1.6E+01	4.4E+01	4.8E+02	5.6E+03	6.7E+04	6.7E+05	5.9E+06
AC225	1.4E+04	4.4E+04	5.9E+06	8.1E+08	1.8E+10	4.4E+10	2.3E+09
AC227	7.0E+05	1.4E+06	1.1E+07	1.1E+08	7.0E+08	8.9E+08	8.9E+08
AC228	1.6E+01	4.4E+01	4.8E+02	5.6E+03	6.7E+04	6.7E+05	5.9E+06
TH227	7.0E+05	1.4E+06	1.1E+07	1.1E+08	7.0E+08	8.9E+08	8.9E+08
TH228	7.8E+08	4.4E+08	1.1E+05	4.1E+04	8.5E+04	6.7E+05	5.9E+06
TH229	1.4E+04	4.4E+04	5.9E+06	8.1E+08	1.8E+10	4.4E+10	2.3E+09
TH230	1.8E+07	4.8E+07	7.4E+08	7.4E+09	4.4E+10	1.8E+10	1.2E+10
TH231	5.2E+08	5.2E+08	5.2E+08	5.9E+08	8.9E+08	8.9E+08	8.9E+08
TH232	2.1E+01	4.8E+01	4.8E+02	5.6E+03	6.7E+04	6.7E+05	5.9E+06
TH234	1.2E+10	1.2E+10	1.2E+10	1.2E+10	1.2E+10	1.2E+10	1.2E+10
PA231	1.1E+06	1.8E+06	1.1E+07	1.1E+08	7.0E+08	8.9E+08	8.9E+08
PA233	1.6E+10	1.9E+10	4.8E+10	5.6E+10	5.6E+10	4.1E+10	2.3E+09
PA234M	1.2E+10	1.2E+10	1.2E+10	1.2E+10	1.2E+10	1.2E+10	1.2E+10
PA234	1.5E+07	1.5E+07	1.5E+07	1.5E+07	1.5E+07	1.5E+07	1.5E+07
U232	7.8E+08	4.4E+08	1.1E+05	3.6E+04	2.1E+04	9.3E+01	0.
U233	3.1E+06	7.4E+06	1.5E+08	2.3E+09	2.0E+10	4.4E+10	2.3E+09
U234	5.2E+10	6.7E+10	8.9E+10	8.5E+10	7.0E+10	1.6E+10	1.2E+10
U235	5.2E+08	5.2E+08	5.2E+08	5.9E+08	8.9E+08	8.9E+08	8.9E+08
U236	1.0E+10	1.0E+10	1.0E+10	1.3E+10	1.4E+10	1.3E+10	1.0E+10
U238	1.2E+10	1.2E+10	1.2E+10	1.2E+10	1.2E+10	1.2E+10	1.2E+10
NP236	4.1E+05	4.1E+05	4.1E+05	4.1E+05	2.3E+05	1.0E+03	0.
NP237	1.6E+10	1.9E+10	4.8E+10	5.6E+10	5.6E+10	4.1E+10	2.3E+09
NP239	1.2E+12	1.2E+12	1.1E+12	4.8E+11	1.0E+08	1.0E+04	6.7E+03
PU236	1.1E+06	3.7E+04	3.7E+04	3.6E+04	2.1E+04	9.3E+01	0.
PU239	1.1E+13	1.1E+13	1.1E+13	8.1E+12	6.3E+11	1.0E+04	6.7E+03
PU240	1.4E+13	1.4E+13	1.3E+13	4.8E+12	3.5E+08	3.4E+04	3.1E+04
PU241	9.3E+14	5.2E+13	1.2E+10	5.9E+09	3.7E+06	0.	0.
PU242	1.1E+11	1.1E+11	1.1E+11	1.0E+11	8.9E+10	1.8E+10	1.8E+03
AM241	1.8E+14	1.9E+14	4.4E+13	5.9E+09	3.7E+06	0.	0.
AM243	1.2E+12	1.2E+12	1.1E+12	4.8E+11	1.0E+08	1.0E+04	6.7E+03

TABLE 3A. FISSIONPRODUCTS IN BWR-FUEL
33 GWD/TONU(2.8%) BQ/TONU

NUCLIDE	40Y	100Y	1 000Y	10 000Y	100 000Y	1MY	10MY
H 3	2.1E+12	7.0E+10	8.1E-12	0.	0.	0.	0.
BE 10	1.1E+05	1.1E+05	1.1E+05	1.1E+05	1.0E+05	7.0E+04	1.4E+03
C 14	4.4E+06	3.7E+06	1.3E+06	2.4E+01	0.	0.	0.
SE 79	1.5E+10	1.5E+10	1.4E+10	1.3E+10	5.2E+09	3.4E+05	0.
KR 81	1.9E+04	1.9E+04	1.9E+04	1.8E+04	1.3E+04	7.0E+02	8.5E-11
KR 85	2.3E+13	4.8E+11	2.6E-14	0.	0.	0.	0.
RB 87	7.4E+05	7.4E+05	7.4E+05	7.4E+05	7.4E+05	7.4E+05	7.4E+05
SR 90	9.6E+14	2.3E+14	1.1E+05	0.	0.	0.	0.
Y 90	9.6E+14	2.3E+14	1.1E+05	0.	0.	0.	0.
ZR 93	6.3E+10	6.3E+10	6.3E+10	6.3E+10	6.3E+10	4.1E+10	7.0E+08
NB 93M	5.6E+10	6.3E+10	6.3E+10	6.3E+10	5.9E+10	4.1E+10	6.7E+08
NB 94	5.6E+06	5.6E+06	5.6E+06	4.1E+06	1.9E+05	8.5E-09	0.
TC 99	4.8E+11	4.8E+11	4.8E+11	4.8E+11	3.5E+11	1.9E+10	3.6E-03
PD107	4.8E+09	4.8E+09	4.8E+09	4.8E+09	4.8E+09	4.1E+09	1.6E+09
AG108	9.3E+04	6.7E+04	4.8E+02	2.3E-19	0.	0.	0.
AG108M	1.0E+06	7.4E+05	5.6E+03	2.6E-18	0.	0.	0.
CD113M	3.1E+11	1.8E+10	4.8E-09	0.	0.	0.	0.
IN115	4.8E-01	4.8E-01	4.8E-01	4.8E-01	4.8E-01	4.8E-01	4.8E-01
SN121M	4.4E+09	2.0E+09	7.4E+03	0.	0.	0.	0.
TE123	8.1E-02	8.1E-02	8.1E-02	8.1E-02	8.1E-02	8.1E-02	8.1E-02
SB1252	1.9E+10	5.9E+03	0.	0.	0.	0.	0.
TE125M	4.8E+09	1.4E+03	0.	0.	0.	0.	0.
SN126	2.8E+10	2.8E+10	2.8E+10	2.6E+10	1.4E+10	2.8E+07	0.
SB126	4.1E+09	4.1E+09	4.1E+09	4.1E+09	2.0E+09	3.7E+06	0.
SB126M	2.8E+10	2.8E+10	2.8E+10	2.6E+10	1.4E+10	2.8E+07	0.
I129	1.2E+09	1.2E+09	1.2E+09	1.2E+09	1.2E+09	1.1E+09	7.4E+08
CS134	7.4E+09	1.3E+01	0.	0.	0.	0.	0.
CS135	1.8E+10	1.8E+10	1.8E+10	1.8E+10	1.7E+10	1.3E+10	8.9E+08
CS137	1.5E+15	3.7E+14	3.5E+05	0.	0.	0.	0.
BA137M	1.4E+15	3.5E+14	3.3E+05	0.	0.	0.	0.
LA138	3.7E+00	3.7E+00	3.7E+00	3.7E+00	3.7E+00	3.7E+00	3.7E+00
CE142	1.0E+06	1.0E+06	1.0E+06	1.0E+06	1.0E+06	1.0E+06	1.0E+06
ND144	5.9E+01	5.9E+01	5.9E+01	5.9E+01	5.9E+01	5.9E+01	5.9E+01
PM147	1.0E+11	1.4E+04	0.	0.	0.	0.	0.
SM147	1.8E+05	1.8E+05	1.8E+05	1.8E+05	1.8E+05	1.8E+05	1.8E+05
SM148	2.1E+00	2.1E+00	2.1E+00	2.1E+00	2.1E+00	2.1E+00	2.1E+00
SM149	2.4E-02	2.4E-02	2.4E-02	2.4E-02	2.4E-02	2.4E-02	2.4E-02
SM151	9.6E+12	5.9E+12	5.9E+09	0.	0.	0.	0.
EU152	4.4E+10	2.1E+09	2.6E-11	0.	0.	0.	0.
GD152	2.7E-02	2.8E-02	2.8E-02	2.8E-02	2.8E-02	2.8E-02	2.8E-02
EU154	1.6E+13	1.3E+11	0.	0.	0.	0.	0.
EU155	9.3E+11	2.1E+08	0.	0.	0.	0.	0.
HO166M	1.1E+08	1.1E+08	6.3E+07	3.5E+05	9.3E-18	0.	0.
TM171	1.4E+01	5.6E-09	0.	0.	0.	0.	0.

TABLE 3B. CONTENT OF HEAVY NUCLIDES IN BWR-FUEL
33 GWD/TONU (2.8%) BQ/TONU

NUCLIDE	40Y	100Y	1 000Y	10 000Y	100 000Y	1MY	10MY
TL207	7.8E+05	1.5E+06	1.1E+07	1.0E+08	6.7E+08	8.5E+08	8.5E+08
TL208	1.9E+08	1.0E+08	2.6E+04	9.6E+03	2.5E+04	2.1E+05	1.9E+06
TL209	2.7E+02	7.8E+02	1.1E+05	1.6E+07	3.6E+08	8.9E+08	4.4E+07
PB209	1.2E+04	3.6E+04	5.2E+06	7.4E+08	1.7E+10	4.1E+10	2.1E+09
PB210	4.8E+04	4.8E+05	1.1E+08	5.2E+09	4.1E+10	1.7E+10	1.2E+10
PB211	7.8E+05	1.5E+06	1.1E+07	1.0E+08	6.7E+08	8.5E+08	8.5E+08
PB212	5.2E+08	2.8E+08	7.4E+04	2.6E+04	7.0E+04	5.9E+05	5.2E+06
PB214	1.4E+05	8.9E+05	1.1E+08	5.2E+09	4.1E+10	1.7E+10	1.2E+10
BI210	4.8E+04	4.8E+05	1.1E+08	5.2E+09	4.1E+10	1.7E+10	1.2E+10
BI211	7.8E+05	1.5E+06	1.1E+07	1.0E+08	6.7E+08	8.5E+08	8.5E+08
BI212	5.2E+08	2.8E+08	7.4E+04	2.6E+04	7.0E+04	5.9E+05	5.2E+06
BI213	1.2E+04	3.6E+04	5.2E+06	7.4E+08	1.7E+10	4.1E+10	2.1E+09
BI214	1.4E+05	8.9E+05	1.1E+08	5.2E+09	4.1E+10	1.7E+10	1.2E+10
PO210	4.8E+04	4.8E+05	1.1E+08	5.2E+09	4.1E+10	1.7E+10	1.2E+10
PO211	2.1E+03	4.1E+03	3.1E+04	2.8E+05	1.9E+06	2.4E+06	2.3E+06
PO212	3.3E+08	1.9E+08	4.8E+04	1.7E+04	4.4E+04	3.7E+05	3.3E+06
PO213	1.2E+04	3.6E+04	5.2E+06	7.0E+08	1.6E+10	4.1E+10	2.0E+09
PO214	1.4E+05	8.9E+05	1.1E+08	5.2E+09	4.1E+10	1.7E+10	1.2E+10
PO215	7.8E+05	1.5E+06	1.1E+07	1.0E+08	6.7E+08	8.5E+08	8.5E+08
PO216	5.2E+08	2.8E+08	7.4E+04	2.6E+04	7.0E+04	5.9E+05	5.2E+06
PO218	1.4E+05	8.9E+05	1.1E+08	5.2E+09	4.1E+10	1.7E+10	1.2E+10
AT217	1.2E+04	3.5E+04	5.2E+06	7.4E+08	1.7E+10	4.1E+10	2.1E+09
RN219	7.8E+05	1.5E+06	1.1E+07	1.0E+08	6.7E+08	8.5E+08	8.5E+08
RN220	5.2E+08	2.8E+08	7.4E+04	2.6E+04	7.0E+04	5.9E+05	5.2E+06
RN222	1.4E+05	8.9E+05	1.1E+08	5.2E+09	4.1E+10	1.7E+10	1.2E+10
FR221	1.2E+04	3.6E+04	5.2E+06	7.4E+08	1.7E+10	4.1E+10	2.1E+09
FR223	1.0E+04	2.0E+04	1.5E+05	1.4E+06	9.3E+06	1.1E+07	1.1E+07
RA223	7.8E+05	1.5E+06	1.1E+07	1.0E+08	6.7E+08	8.5E+08	8.5E+08
RA224	5.2E+08	2.8E+08	7.4E+04	2.6E+04	7.0E+04	5.9E+05	5.2E+06
RA225	1.2E+04	3.6E+04	5.2E+06	7.4E+08	1.7E+10	4.1E+10	2.1E+09
RA226	1.4E+05	8.9E+05	1.1E+08	5.2E+09	4.1E+10	1.7E+10	1.2E+10
RA228	1.4E+01	4.1E+01	4.4E+02	4.8E+03	5.9E+04	5.9E+05	5.2E+06
AC225	1.2E+04	3.6E+04	5.2E+06	7.4E+08	1.7E+10	4.1E+10	2.1E+09
AC227	7.8E+05	1.5E+06	1.1E+07	1.0E+08	6.7E+08	8.5E+08	8.5E+08
AC228	1.4E+01	4.1E+01	4.4E+02	4.8E+03	5.9E+04	5.9E+05	5.2E+06
TH227	7.4E+05	1.4E+06	1.1E+07	1.0E+08	6.7E+08	8.5E+08	8.1E+08
TH228	5.2E+08	2.8E+08	7.4E+04	2.6E+04	7.0E+04	5.9E+05	5.2E+06
TH229	1.2E+04	3.6E+04	5.2E+06	7.4E+08	1.7E+10	4.1E+10	2.1E+09
TH230	1.6E+07	4.4E+07	6.3E+08	6.7E+09	4.1E+10	1.7E+10	1.2E+10
TH231	4.8E+08	4.8E+08	4.8E+08	5.6E+08	8.1E+08	8.5E+08	8.5E+08
TH232	1.8E+01	4.4E+01	4.4E+02	4.8E+03	5.9E+04	5.9E+05	5.2E+06
TH234	1.2E+10	1.2E+10	1.2E+10	1.2E+10	1.2E+10	1.2E+10	1.2E+10
PA231	1.2E+06	1.8E+06	1.1E+07	1.0E+08	6.7E+08	8.5E+08	8.5E+08
PA233	1.3E+10	1.6E+10	4.4E+10	5.2E+10	5.2E+10	3.7E+10	2.1E+09
PA234M	1.2E+10	1.2E+10	1.2E+10	1.2E+10	1.2E+10	1.2E+10	1.2E+10
PA234	1.5E+07	1.5E+07	1.5E+07	1.5E+07	1.5E+07	1.5E+07	1.5E+07
U232	4.8E+08	2.8E+08	7.0E+04	2.1E+04	1.3E+04	5.6E+01	0.
U233	2.5E+06	6.3E+06	1.4E+08	2.1E+09	1.8E+10	4.1E+10	2.1E+09
U234	4.4E+10	5.9E+10	7.8E+10	7.4E+10	5.9E+10	1.6E+10	1.2E+10
U235	4.8E+08	4.8E+08	4.8E+08	5.6E+08	8.1E+08	8.5E+08	8.5E+08
U236	8.5E+09	8.5E+09	8.9E+09	1.1E+10	1.2E+10	1.2E+10	8.9E+09
U238	1.2E+10	1.2E+10	1.2E+10	1.2E+10	1.2E+10	1.2E+10	1.2E+10
NP236	2.6E+05	2.6E+05	2.5E+05	2.4E+05	1.4E+05	6.3E+02	0.
NP237	1.3E+10	1.6E+10	4.4E+10	5.2E+10	5.2E+10	3.7E+10	2.1E+09
NP239	1.0E+12	1.0E+12	9.6E+11	4.1E+11	8.5E+07	6.3E+03	4.1E+03
PU236	5.6E+05	2.3E+04	2.3E+04	2.1E+04	1.3E+04	5.6E+01	0.
PU239	1.0E+13	1.0E+13	9.6E+12	8.1E+12	5.9E+11	6.3E+03	4.1E+03
PU240	1.3E+13	1.3E+13	1.1E+13	4.4E+12	3.2E+08	2.1E+04	2.0E+04
PU241	8.5E+14	4.8E+13	8.9E+09	4.4E+09	2.8E+06	0.	0.
PU242	9.6E+10	9.6E+10	9.6E+10	9.3E+10	7.8E+10	1.6E+10	1.6E+03
AM241	1.7E+14	1.8E+14	4.1E+13	4.4E+09	2.8E+06	0.	0.
AM243	1.0E+12	1.0E+12	9.6E+11	4.1E+11	8.5E+07	6.3E+03	4.1E+03

TABLE 4. THE TOTAL RADIOACTIVITY(BEQUERELS)
REACTORTYPE PWR
SPECIFIC POWER 38.5 (W/G)

TIME YEARS	BURN-UP GWD/TU (ENRICHMENT) (%) 33(3.2)	38(3.2)	38(3.6)	45(3.2)
0.	7.9E+18	8.1E+18	7.9E+18	8.4E+18
1.0E+00	8.9E+16	9.0E+16	8.9E+16	9.6E+16
2.0E+00	5.0E+16	5.2E+16	5.1E+16	5.8E+16
3.0E+00	3.4E+16	3.6E+16	3.6E+16	4.1E+16
4.0E+00	2.6E+16	2.8E+16	2.8E+16	3.3E+16
5.0E+00	2.2E+16	2.4E+16	2.4E+16	2.8E+16
6.0E+00	1.9E+16	2.1E+16	2.1E+16	2.5E+16
7.0E+00	1.8E+16	2.0E+16	2.0E+16	2.3E+16
8.0E+00	1.7E+16	1.9E+16	1.9E+16	2.2E+16
9.0E+00	1.6E+16	1.8E+16	1.8E+16	2.1E+16
1.0E+01	1.5E+16	1.7E+16	1.7E+16	2.0E+16
1.2E+01	1.4E+16	1.6E+16	1.6E+16	1.8E+16
1.4E+01	1.3E+16	1.5E+16	1.5E+16	1.7E+16
1.6E+01	1.2E+16	1.4E+16	1.4E+16	1.6E+16
1.8E+01	1.1E+16	1.3E+16	1.3E+16	1.5E+16
2.0E+01	1.1E+16	1.2E+16	1.2E+16	1.4E+16
2.2E+01	1.0E+16	1.1E+16	1.1E+16	1.3E+16
2.4E+01	9.6E+15	1.1E+16	1.1E+16	1.3E+16
2.6E+01	9.1E+15	1.0E+16	1.0E+16	1.2E+16
2.8E+01	8.6E+15	9.6E+15	9.6E+15	1.1E+16
3.0E+01	8.1E+15	9.1E+15	9.1E+15	1.1E+16
3.5E+01	7.1E+15	7.9E+15	8.0E+15	9.3E+15
4.0E+01	6.2E+15	7.0E+15	7.0E+15	8.2E+15
6.0E+01	3.8E+15	4.2E+15	4.3E+15	5.0E+15
1.0E+02	1.5E+15	1.7E+15	1.7E+15	2.0E+15
3.0E+02	1.7E+14	1.9E+14	1.9E+14	2.4E+14
1.0E+03	6.6E+13	7.2E+13	6.9E+13	8.8E+13
3.0E+03	2.4E+13	2.5E+13	2.4E+13	3.0E+13
1.0E+04	1.5E+13	1.5E+13	1.5E+13	1.8E+13
3.0E+04	6.5E+12	6.8E+12	6.7E+12	8.1E+12
1.0E+05	2.0E+12	2.2E+12	2.2E+12	2.6E+12
3.0E+05	1.3E+12	1.5E+12	1.5E+12	1.8E+12
1.0E+06	8.1E+11	8.9E+11	8.8E+11	1.1E+12
1.0E+07	2.1E+11	2.1E+11	2.1E+11	2.2E+11

TABLE 5. THE RADIOACTIVITY FROM THE ALFADECAY(BEQUERELS)
REACTORTYPE PWR
SPECIFIC POWER 38.5 (W/G)

TIME YEARS	BURN-UP GWD/TU (ENRICHMENT) (%) 33(3.2)	38(3.2)	38(3.6)	45(3.2)
0.	2.0E+14	3.2E+14	2.6E+14	6.0E+14
1.0E+00	2.1E+14	3.3E+14	2.8E+14	6.2E+14
2.0E+00	2.2E+14	3.4E+14	2.8E+14	6.2E+14
3.0E+00	2.2E+14	3.4E+14	2.9E+14	6.2E+14
4.0E+00	2.3E+14	3.4E+14	2.9E+14	6.1E+14
5.0E+00	2.3E+14	3.4E+14	2.9E+14	6.1E+14
6.0E+00	2.4E+14	3.5E+14	3.0E+14	6.1E+14
7.0E+00	2.4E+14	3.5E+14	3.0E+14	6.0E+14
8.0E+00	2.4E+14	3.5E+14	3.0E+14	6.0E+14
9.0E+00	2.5E+14	3.5E+14	3.0E+14	6.0E+14
1.0E+01	2.5E+14	3.5E+14	3.1E+14	5.9E+14
1.2E+01	2.5E+14	3.5E+14	3.1E+14	5.9E+14
1.4E+01	2.6E+14	3.5E+14	3.1E+14	5.8E+14
1.6E+01	2.6E+14	3.5E+14	3.1E+14	5.7E+14
1.8E+01	2.7E+14	3.5E+14	3.2E+14	5.6E+14
2.0E+01	2.7E+14	3.5E+14	3.2E+14	5.6E+14
2.2E+01	2.7E+14	3.5E+14	3.2E+14	5.5E+14
2.4E+01	2.7E+14	3.5E+14	3.2E+14	5.4E+14
2.6E+01	2.7E+14	3.5E+14	3.2E+14	5.4E+14
2.8E+01	2.7E+14	3.5E+14	3.2E+14	5.3E+14
3.0E+01	2.8E+14	3.5E+14	3.2E+14	5.2E+14
3.5E+01	2.8E+14	3.5E+14	3.2E+14	5.1E+14
4.0E+01	2.8E+14	3.4E+14	3.1E+14	4.9E+14
6.0E+01	2.7E+14	3.2E+14	3.0E+14	4.4E+14
1.0E+02	2.4E+14	2.8E+14	2.7E+14	3.7E+14
3.0E+02	1.6E+14	1.8E+14	1.7E+14	2.2E+14
1.0E+03	6.5E+13	7.0E+13	6.7E+13	8.5E+13
3.0E+03	2.2E+13	2.3E+13	2.3E+13	2.8E+13
1.0E+04	1.3E+13	1.4E+13	1.4E+13	1.7E+13
3.0E+04	5.5E+12	5.7E+12	5.6E+12	6.8E+12
1.0E+05	9.4E+11	1.0E+12	9.9E+11	1.2E+12
3.0E+05	3.2E+11	3.7E+11	3.6E+11	4.6E+11
1.0E+06	2.1E+11	2.3E+11	2.2E+11	2.7E+11
1.0E+07	6.5E+10	6.6E+10	6.6E+10	6.8E+10

TABLE 6. THE THERMAL POWER(WATTS)
REACTORTYPE PWR
SPECIFIC POWER 38.5 (W/G)

TIME YEARS	BURN-UP GWD/TU (ENRICHMENT) (%) 33(3.2)	38(3.2)	38(3.6)	45(3.2)
0.	2.1E+06	2.2E+06	2.2E+06	2.2E+06
1.0E+00	9.5E+03	9.9E+03	9.6E+03	1.1E+04
2.0E+00	5.0E+03	5.4E+03	5.2E+03	6.3E+03
3.0E+00	3.2E+03	3.5E+03	3.4E+03	4.2E+03
4.0E+00	2.2E+03	2.6E+03	2.5E+03	3.2E+03
5.0E+00	1.8E+03	2.1E+03	2.0E+03	2.6E+03
6.0E+00	1.5E+03	1.8E+03	1.7E+03	2.3E+03
7.0E+00	1.3E+03	1.6E+03	1.6E+03	2.1E+03
8.0E+00	1.2E+03	1.5E+03	1.4E+03	1.9E+03
9.0E+00	1.2E+03	1.4E+03	1.4E+03	1.8E+03
1.0E+01	1.1E+03	1.3E+03	1.3E+03	1.7E+03
1.2E+01	1.1E+03	1.2E+03	1.2E+03	1.6E+03
1.4E+01	1.0E+03	1.2E+03	1.2E+03	1.5E+03
1.6E+01	9.6E+02	1.1E+03	1.1E+03	1.5E+03
1.8E+01	9.2E+02	1.1E+03	1.1E+03	1.4E+03
2.0E+01	8.9E+02	1.0E+03	1.0E+03	1.3E+03
2.2E+01	8.6E+02	1.0E+03	9.8E+02	1.3E+03
2.4E+01	8.3E+02	9.7E+02	9.5E+02	1.2E+03
2.6E+01	8.0E+02	9.4E+02	9.2E+02	1.2E+03
2.8E+01	7.7E+02	9.0E+02	8.9E+02	1.2E+03
3.0E+01	7.5E+02	8.7E+02	8.6E+02	1.1E+03
3.5E+01	6.9E+02	8.1E+02	7.9E+02	1.0E+03
4.0E+01	6.4E+02	7.4E+02	7.3E+02	9.4E+02
6.0E+01	4.8E+02	5.6E+02	5.4E+02	7.1E+02
1.0E+02	3.1E+02	3.6E+02	3.5E+02	4.5E+02
3.0E+02	1.4E+02	1.6E+02	1.5E+02	2.0E+02
1.0E+03	5.7E+01	6.1E+01	5.9E+01	7.5E+01
3.0E+03	1.9E+01	2.0E+01	1.9E+01	2.4E+01
1.0E+04	1.1E+01	1.2E+01	1.1E+01	1.4E+01
3.0E+04	4.7E+00	5.0E+00	4.8E+00	5.9E+00
1.0E+05	1.0E+00	1.1E+00	1.1E+00	1.4E+00
3.0E+05	6.4E-01	7.2E-01	7.2E-01	9.0E-01
1.0E+06	4.4E-01	4.8E-01	4.7E-01	5.8E-01
1.0E+07	1.2E-01	1.2E-01	1.2E-01	1.2E-01

TABLE 7. THE TOTAL NEUTRON EMISSION(NEUTRONS/SEC)
REACTORTYPE PWR
SPECIFIC POWER 38.5 (W/G)

TIME YEARS	BURN-UP GWD/TU (ENRICHMENT) (%) 33(3.2)	38(3.2)	38(3.6)	45(3.2)
0.	1.2E+09	1.9E+09	1.6E+09	3.2E+09
1.0E+00	5.0E+08	8.9E+08	6.9E+08	1.8E+09
2.0E+00	3.5E+08	6.5E+08	4.8E+08	1.4E+09
3.0E+00	3.1E+08	5.9E+08	4.3E+08	1.3E+09
4.0E+00	2.9E+08	5.6E+08	4.0E+08	1.3E+09
5.0E+00	2.8E+08	5.3E+08	3.9E+08	1.2E+09
6.0E+00	2.7E+08	5.1E+08	3.7E+08	1.2E+09
7.0E+00	2.6E+08	5.0E+08	3.6E+08	1.1E+09
8.0E+00	2.5E+08	4.8E+08	3.5E+08	1.1E+09
9.0E+00	2.4E+08	4.6E+08	3.3E+08	1.0E+09
1.0E+01	2.3E+08	4.4E+08	3.2E+08	1.0E+09
1.2E+01	2.2E+08	4.1E+08	3.0E+08	9.3E+08
1.4E+01	2.0E+08	3.8E+08	2.8E+08	8.7E+08
1.6E+01	1.9E+08	3.6E+08	2.6E+08	8.0E+08
1.8E+01	1.7E+08	3.3E+08	2.4E+08	7.5E+08
2.0E+01	1.6E+08	3.1E+08	2.2E+08	6.9E+08
2.2E+01	1.5E+08	2.9E+08	2.1E+08	6.4E+08
2.4E+01	1.4E+08	2.7E+08	2.0E+08	6.0E+08
2.6E+01	1.3E+08	2.5E+08	1.8E+08	5.6E+08
2.8E+01	1.2E+08	2.3E+08	1.7E+08	5.2E+08
3.0E+01	1.2E+08	2.2E+08	1.6E+08	4.8E+08
3.5E+01	9.7E+07	1.8E+08	1.3E+08	4.0E+08
4.0E+01	8.2E+07	1.5E+08	1.1E+08	3.4E+08
6.0E+01	4.5E+07	7.9E+07	5.9E+07	1.7E+08
1.0E+02	1.8E+07	2.8E+07	2.2E+07	5.5E+07
3.0E+02	8.2E+06	1.1E+07	9.2E+06	1.8E+07
1.0E+03	4.9E+06	6.8E+06	5.7E+06	1.3E+07
3.0E+03	3.1E+06	4.6E+06	3.7E+06	9.1E+06
1.0E+04	2.0E+06	2.7E+06	2.3E+06	4.7E+06
3.0E+04	1.3E+06	1.7E+06	1.5E+06	2.3E+06
1.0E+05	1.6E+06	1.9E+06	1.8E+06	2.6E+06
3.0E+05	1.9E+06	2.2E+06	2.1E+06	2.9E+06
1.0E+06	1.4E+06	1.5E+06	1.5E+06	1.9E+06
1.0E+07	1.6E+05	1.7E+05	1.7E+05	1.8E+05

TABLE 8. THE TOTAL RADIOACTIVITY(BEQUERELS)
REACTORTYPE BWR
SPECIFIC POWER 22.0 (W/G)

TIME YEARS	BURN-UP GWD/TU (ENRICHMENT) (%) 28(2.8)	33(2.8)	38(2.8)	38(3.2)
0.	4.6E+18	4.7E+18	4.8E+18	4.8E+18
1.0E+00	6.2E+16	6.7E+16	7.0E+16	6.9E+16
2.0E+00	3.7E+16	4.0E+16	4.3E+16	4.3E+16
3.0E+00	2.6E+16	2.9E+16	3.2E+16	3.2E+16
4.0E+00	2.1E+16	2.3E+16	2.6E+16	2.6E+16
5.0E+00	1.8E+16	2.0E+16	2.2E+16	2.2E+16
6.0E+00	1.6E+16	1.8E+16	2.0E+16	2.0E+16
7.0E+00	1.5E+16	1.7E+16	1.9E+16	1.9E+16
8.0E+00	1.4E+16	1.6E+16	1.8E+16	1.8E+16
9.0E+00	1.3E+16	1.5E+16	1.7E+16	1.7E+16
1.0E+01	1.3E+16	1.5E+16	1.6E+16	1.6E+16
1.2E+01	1.2E+16	1.4E+16	1.5E+16	1.5E+16
1.4E+01	1.1E+16	1.3E+16	1.4E+16	1.4E+16
1.6E+01	1.0E+16	1.2E+16	1.3E+16	1.3E+16
1.8E+01	9.7E+15	1.1E+16	1.2E+16	1.2E+16
2.0E+01	9.1E+15	1.0E+16	1.2E+16	1.2E+16
2.2E+01	8.6E+15	9.9E+15	1.1E+16	1.1E+16
2.4E+01	8.1E+15	9.3E+15	1.0E+16	1.0E+16
2.6E+01	7.7E+15	8.8E+15	9.9E+15	9.9E+15
2.8E+01	7.3E+15	8.3E+15	9.3E+15	9.4E+15
3.0E+01	6.9E+15	7.9E+15	8.8E+15	8.9E+15
3.5E+01	6.0E+15	6.9E+15	7.7E+15	7.8E+15
4.0E+01	5.3E+15	6.0E+15	6.8E+15	6.8E+15
6.0E+01	3.2E+15	3.7E+15	4.1E+15	4.1E+15
1.0E+02	1.3E+15	1.5E+15	1.7E+15	1.7E+15
3.0E+02	1.6E+14	1.8E+14	2.0E+14	1.9E+14
1.0E+03	6.1E+13	6.7E+13	7.2E+13	6.9E+13
3.0E+03	2.2E+13	2.3E+13	2.5E+13	2.4E+13
1.0E+04	1.3E+13	1.4E+13	1.5E+13	1.5E+13
3.0E+04	6.0E+12	6.4E+12	6.8E+12	6.6E+12
1.0E+05	1.8E+12	2.0E+12	2.2E+12	2.2E+12
3.0E+05	1.2E+12	1.4E+12	1.5E+12	1.5E+12
1.0E+06	7.3E+11	8.2E+11	8.9E+11	8.9E+11
1.0E+07	2.1E+11	2.1E+11	2.1E+11	2.1E+11

TABLE 9. THE RADIOACTIVITY FROM THE ALFADECAY(BEQUERELS)
REACTORTYPE BWR
SPECIFIC POWER 22.0 (W/G)

TIME YEARS	BURN-UP GWD/TU (ENRICHMENT) (%) 28(2.8)	33(2.8)	38(2.8)	38(3.2)
0.	1.5E+14	2.6E+14	4.2E+14	3.4E+14
1.0E+00	1.7E+14	2.8E+14	4.3E+14	3.6E+14
2.0E+00	1.7E+14	2.8E+14	4.4E+14	3.6E+14
3.0E+00	1.8E+14	2.9E+14	4.4E+14	3.7E+14
4.0E+00	1.8E+14	2.9E+14	4.4E+14	3.7E+14
5.0E+00	1.9E+14	2.9E+14	4.3E+14	3.7E+14
6.0E+00	1.9E+14	2.9E+14	4.3E+14	3.7E+14
7.0E+00	2.0E+14	3.0E+14	4.3E+14	3.7E+14
8.0E+00	2.0E+14	3.0E+14	4.3E+14	3.7E+14
9.0E+00	2.0E+14	3.0E+14	4.3E+14	3.7E+14
1.0E+01	2.1E+14	3.0E+14	4.3E+14	3.7E+14
1.2E+01	2.1E+14	3.0E+14	4.3E+14	3.7E+14
1.4E+01	2.2E+14	3.1E+14	4.2E+14	3.7E+14
1.6E+01	2.2E+14	3.1E+14	4.2E+14	3.7E+14
1.8E+01	2.2E+14	3.1E+14	4.2E+14	3.7E+14
2.0E+01	2.3E+14	3.1E+14	4.1E+14	3.7E+14
2.2E+01	2.3E+14	3.1E+14	4.1E+14	3.7E+14
2.4E+01	2.3E+14	3.1E+14	4.1E+14	3.7E+14
2.6E+01	2.4E+14	3.1E+14	4.0E+14	3.6E+14
2.8E+01	2.4E+14	3.1E+14	4.0E+14	3.6E+14
3.0E+01	2.4E+14	3.1E+14	3.9E+14	3.6E+14
3.5E+01	2.4E+14	3.1E+14	3.9E+14	3.5E+14
4.0E+01	2.4E+14	3.1E+14	3.8E+14	3.5E+14
6.0E+01	2.4E+14	2.9E+14	3.4E+14	3.2E+14
1.0E+02	2.2E+14	2.6E+14	3.0E+14	2.8E+14
3.0E+02	1.5E+14	1.7E+14	1.8E+14	1.7E+14
1.0E+03	5.9E+13	6.5E+13	6.9E+13	6.7E+13
3.0E+03	2.0E+13	2.2E+13	2.3E+13	2.2E+13
1.0E+04	1.2E+13	1.3E+13	1.4E+13	1.3E+13
3.0E+04	5.2E+12	5.4E+12	5.6E+12	5.5E+12
1.0E+05	8.7E+11	9.4E+11	1.0E+12	9.9E+11
3.0E+05	2.8E+11	3.3E+11	3.8E+11	3.8E+11
1.0E+06	1.9E+11	2.1E+11	2.3E+11	2.3E+11
1.0E+07	6.3E+10	6.4E+10	6.4E+10	6.5E+10

TABLE 10. THE THERMAL POWER(WATTS)
REACTORTYPE BWR
SPECIFIC POWER 22.0 (W/G)

TIME YEARS	BURN-UP GWD/TU (ENRICHMENT) (%)			
	28(2.8)	33(2.8)	38(2.8)	38(3.2)
0.	1.2E+06	1.3E+06	1.3E+06	1.3E+06
1.0E+00	6.5E+03	7.1E+03	7.7E+03	7.4E+03
2.0E+00	3.5E+03	4.0E+03	4.5E+03	4.4E+03
3.0E+00	2.3E+03	2.7E+03	3.1E+03	3.0E+03
4.0E+00	1.7E+03	2.0E+03	2.4E+03	2.3E+03
5.0E+00	1.4E+03	1.7E+03	2.0E+03	1.9E+03
6.0E+00	1.2E+03	1.5E+03	1.7E+03	1.7E+03
7.0E+00	1.1E+03	1.3E+03	1.6E+03	1.5E+03
8.0E+00	1.0E+03	1.2E+03	1.5E+03	1.4E+03
9.0E+00	9.6E+02	1.2E+03	1.4E+03	1.4E+03
1.0E+01	9.3E+02	1.1E+03	1.4E+03	1.3E+03
1.2E+01	8.7E+02	1.1E+03	1.3E+03	1.2E+03
1.4E+01	8.3E+02	1.0E+03	1.2E+03	1.2E+03
1.6E+01	8.0E+02	9.7E+02	1.2E+03	1.1E+03
1.8E+01	7.7E+02	9.3E+02	1.1E+03	1.1E+03
2.0E+01	7.4E+02	9.0E+02	1.1E+03	1.0E+03
2.2E+01	7.2E+02	8.6E+02	1.0E+03	1.0E+03
2.4E+01	6.9E+02	8.4E+02	9.9E+02	9.7E+02
2.6E+01	6.7E+02	8.1E+02	9.6E+02	9.3E+02
2.8E+01	6.5E+02	7.8E+02	9.2E+02	9.0E+02
3.0E+01	6.3E+02	7.6E+02	8.9E+02	8.7E+02
3.5E+01	5.8E+02	7.0E+02	8.2E+02	8.0E+02
4.0E+01	5.4E+02	6.5E+02	7.6E+02	7.4E+02
6.0E+01	4.1E+02	4.9E+02	5.7E+02	5.6E+02
1.0E+02	2.7E+02	3.2E+02	3.7E+02	3.6E+02
3.0E+02	1.3E+02	1.5E+02	1.6E+02	1.6E+02
1.0E+03	5.2E+01	5.7E+01	6.1E+01	5.9E+01
3.0E+03	1.7E+01	1.8E+01	1.9E+01	1.9E+01
1.0E+04	1.0E+01	1.1E+01	1.2E+01	1.1E+01
3.0E+04	4.5E+00	4.6E+00	4.8E+00	4.7E+00
1.0E+05	9.5E-01	1.0E+00	1.1E+00	1.1E+00
3.0E+05	5.6E-01	6.5E-01	7.4E-01	7.4E-01
1.0E+06	3.9E-01	4.4E-01	4.8E-01	4.8E-01
1.0E+07	1.2E-01	1.2E-01	1.2E-01	1.2E-01

TABLE 11. THE TOTAL NEUTRON EMISSION(NEUTRONS/SEC)
REACTORTYPE BWR
SPECIFIC POWER 22.0 (W/G)

TIME YEARS	BURN-UP GWD/TU (ENRICHMENT) (%) 28(2.8)	33(2.8)	38(2.8)	38(3.2)
0.	1.0E+09	1.6E+09	2.4E+09	2.0E+09
1.0E+00	3.9E+08	7.2E+08	1.2E+09	9.3E+08
2.0E+00	2.5E+08	5.1E+08	9.4E+08	6.9E+08
3.0E+00	2.1E+08	4.5E+08	8.6E+08	6.3E+08
4.0E+00	2.0E+08	4.3E+08	8.1E+08	5.9E+08
5.0E+00	1.9E+08	4.1E+08	7.8E+08	5.7E+08
6.0E+00	1.8E+08	4.0E+08	7.5E+08	5.5E+08
7.0E+00	1.8E+08	3.8E+08	7.3E+08	5.3E+08
8.0E+00	1.7E+08	3.7E+08	7.0E+08	5.1E+08
9.0E+00	1.7E+08	3.6E+08	6.7E+08	4.9E+08
1.0E+01	1.6E+08	3.4E+08	6.5E+08	4.7E+08
1.2E+01	1.5E+08	3.2E+08	6.0E+08	4.4E+08
1.4E+01	1.4E+08	3.0E+08	5.6E+08	4.1E+08
1.6E+01	1.3E+08	2.8E+08	5.2E+08	3.8E+08
1.8E+01	1.2E+08	2.6E+08	4.8E+08	3.5E+08
2.0E+01	1.1E+08	2.4E+08	4.5E+08	3.3E+08
2.2E+01	1.0E+08	2.2E+08	4.2E+08	3.1E+08
2.4E+01	9.8E+07	2.1E+08	3.9E+08	2.8E+08
2.6E+01	9.2E+07	1.9E+08	3.7E+08	2.6E+08
2.8E+01	8.6E+07	1.8E+08	3.4E+08	2.5E+08
3.0E+01	8.0E+07	1.7E+08	3.1E+08	2.3E+08
3.5E+01	6.8E+07	1.4E+08	2.6E+08	1.9E+08
4.0E+01	5.8E+07	1.2E+08	2.2E+08	1.6E+08
6.0E+01	3.2E+07	6.2E+07	1.1E+08	8.3E+07
1.0E+02	1.4E+07	2.3E+07	3.7E+07	2.9E+07
3.0E+02	7.0E+06	9.2E+06	1.3E+07	1.1E+07
1.0E+03	4.1E+06	5.7E+06	8.7E+06	6.9E+06
3.0E+03	2.6E+06	3.7E+06	6.0E+06	4.7E+06
1.0E+04	1.7E+06	2.3E+06	3.4E+06	2.8E+06
3.0E+04	1.1E+06	1.5E+06	1.9E+06	1.7E+06
1.0E+05	1.3E+06	1.7E+06	2.1E+06	2.0E+06
3.0E+05	1.6E+06	2.0E+06	2.3E+06	2.2E+06
1.0E+06	1.2E+06	1.4E+06	1.6E+06	1.5E+06
1.0E+07	1.6E+05	1.6E+05	1.7E+05	1.7E+05

Table 12

The activity (Bequerels) one year after unloading as a function of the burnup for the storage safety of some important nuclides for a PWR and BWR

PWR (38.5 w/g)	Burnup (Gwd/TU)		(3.2 %)
Nuclide	33	38	45
Tc 99	4.86E11	5.45E11	6.18E11
I 129	1.17E9	1.35E9	1.64E9
Cs 135	1.76E10	1.46E10	1.90E10
Pu 239	1.08E13	1.08E13	1.25E13
Np 237	1.16E10	1.39E10	1.79E10
Ra 226	1195	1715	2050
BWR (24.0 w/g)	Burnup (Gwd/TU)		(2.8 %)
Nuclide	28	33	38
Tc 99	4.19E11	4.84E11	5.45E11
I 129	9.92E8	1.18E9	1.36E9
Cs 135	1.53E10	1.80E10	2.07E10
Pu 239	1.03E13	1.04E13	1.04E13
Np 237	9.15E9	1.14E10	1.35E10
Ra 226	1931	2406	2878

Table 13

The maximum values of the activity and corresponding time interval for the most important actinides for a PWR and BWR. As further information the dose conversion factors for ingestion are given.

Reactor	PWR (38.5 w/g 3.2%)			BWR (24.0 w/g 2.8%)			Time of maximum years	Dose conversion factor ingestion /13/ (Sv/Bq)
Nuclide	Burnup (Gwd/TU) 33	38	45	Burnup Gwd/TU) 28	33	38		
U-234	7.6E10	8.8E10	1.1E11	7.7E10	6.5E10	9.0E10	1.0E3	7.1E-8
Th-230	4.5E10	5.1E10	6.3E10	4.5E10	3.9E10	5.2E10	3.0E5	1.5E-7
Ra-226	4.5E10	5.1E10	6.3E10	4.5E10	3.4E10	5.2E10	3.0E5	3.1E-7
Np-237	5.1E10	5.7E10	7.2E10	5.2E10	4.6E10	5.7E10	1.0E4	1.1E-5
U-233	4.0E10	4.4E10	5.6E10	4.0E10	3.5E10	4.4E10	1.0E6	7.2E-8
Th-229	4.0E10	4.4E10	5.6E10	4.0E10	3.5E10	4.4E10	1.0E6	9.4E-7

Table 14 The contents of heavy nuclides at time of discharge as calculated by ORIGEN 2 and CASMO.
Burnup level = 33 000 MWd/TU.

PWR	Content of heavy nuclides (gram/TU)		
Nuclide	ORIGEN 2 (Edlund) 38.5 w/g; 857.14 d	ORIGEN 2 (Etemad/Ekberg) 38.3 w/g; 861.62 d	CASMO (Etemad/Ekberg) 38.3 w/g; 861.62 d
U 235 a)	8158	7958	8318
Reduction U 235	23842	24042	23682
U 238 a)	944458	944100	943200
Reduction U 238 a)	23600	23900	24800
Pu 238 b)	133.4	126.9	127.4
Pu 239 b)	4593	4938	5528
Pu 240 a)	1567	2308	2338
Pu 241 c)	1515	1224	1338
Pu 242 a)	563.8	453.5	545.5
Am 241 b)	38.1	28.2	32.3
Am 243 b)	104.9	86.0	96.4
Cm 242 c)	17.4	11.9	13.0
Cm 244 c)	27.9	24.1	25.6

a) The amount of this nuclide is unaffected during the shut down between the burnup periods, since possible parent and the nuclide itself have long half-lives in relation to the lenght of the shut down.

b) The amount of this nuclide increases during the shut down since its parents have short half-lives in relation to the shut down.

c) The amount of this nuclide decreases during the shut down, which means that the half-life is short in relation to the duration of the shut down.

CALCULATION OF CORE INVENTORY

REACTOR TYPE PWR
SPECIFIC POWER 38.5 W/G

RADIOACTIVITY(TOTAL)

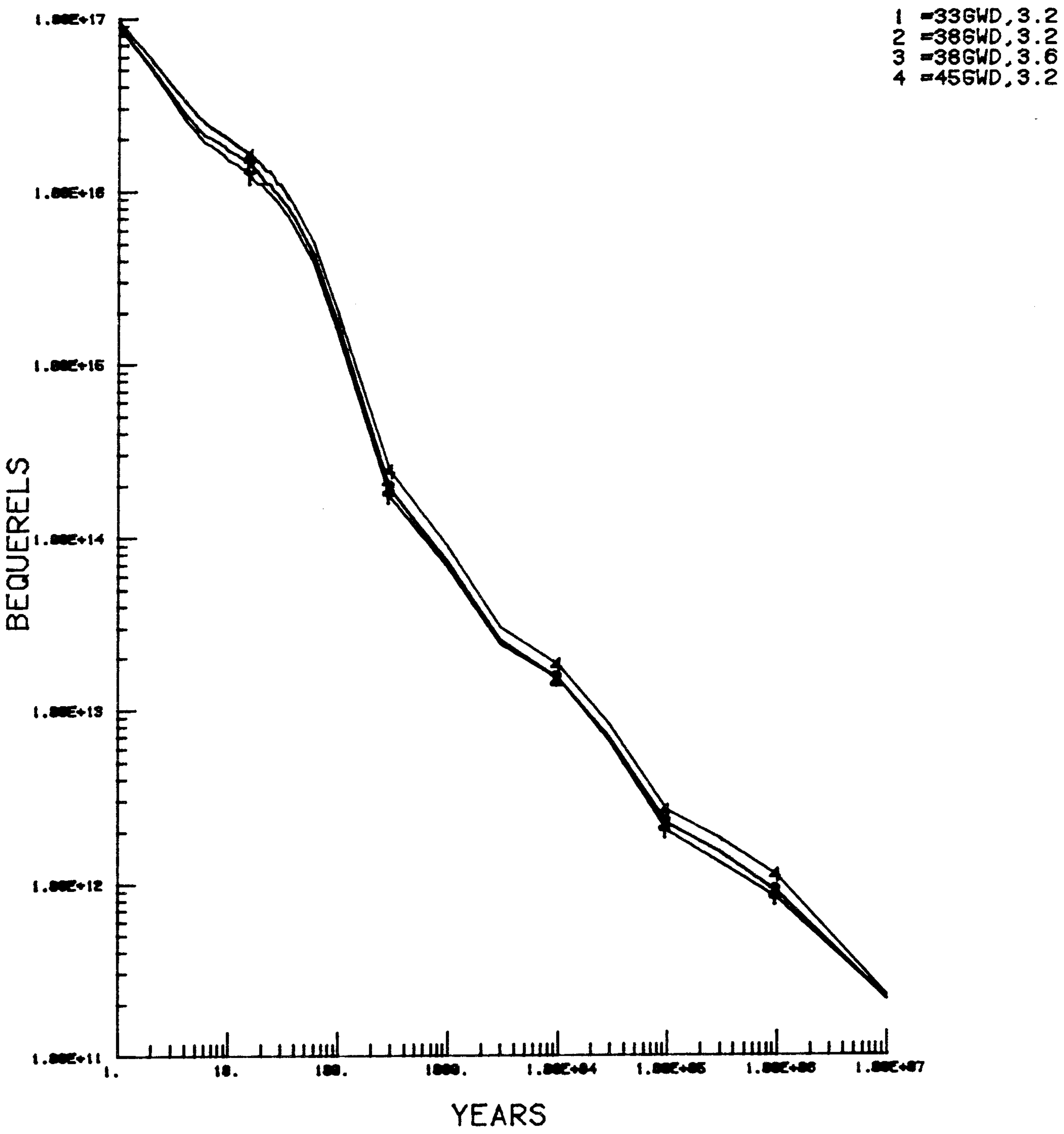

FIG 1

CALCULATION OF CORE INVENTORY

REACTOR TYPE PWR
SPECIFIC POWER 38.5 W/G

RADIOACTIVITY(ALFA)

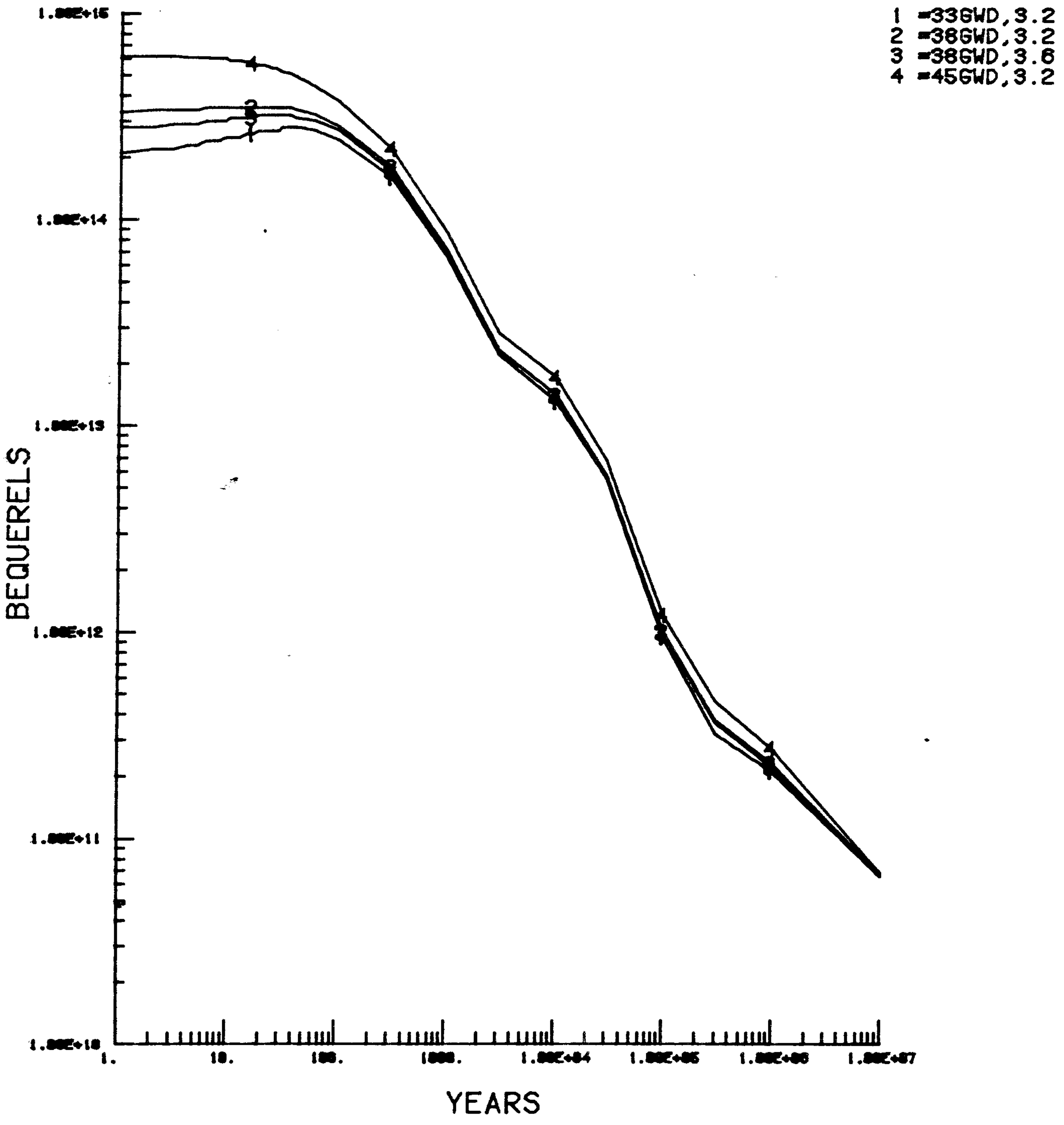

FIG 2

CALCULATION OF CORE INVENTORY

REACTOR TYPE PWR
SPECIFIC POWER 38.5 W/G

THERMAL POWER(TOTAL)

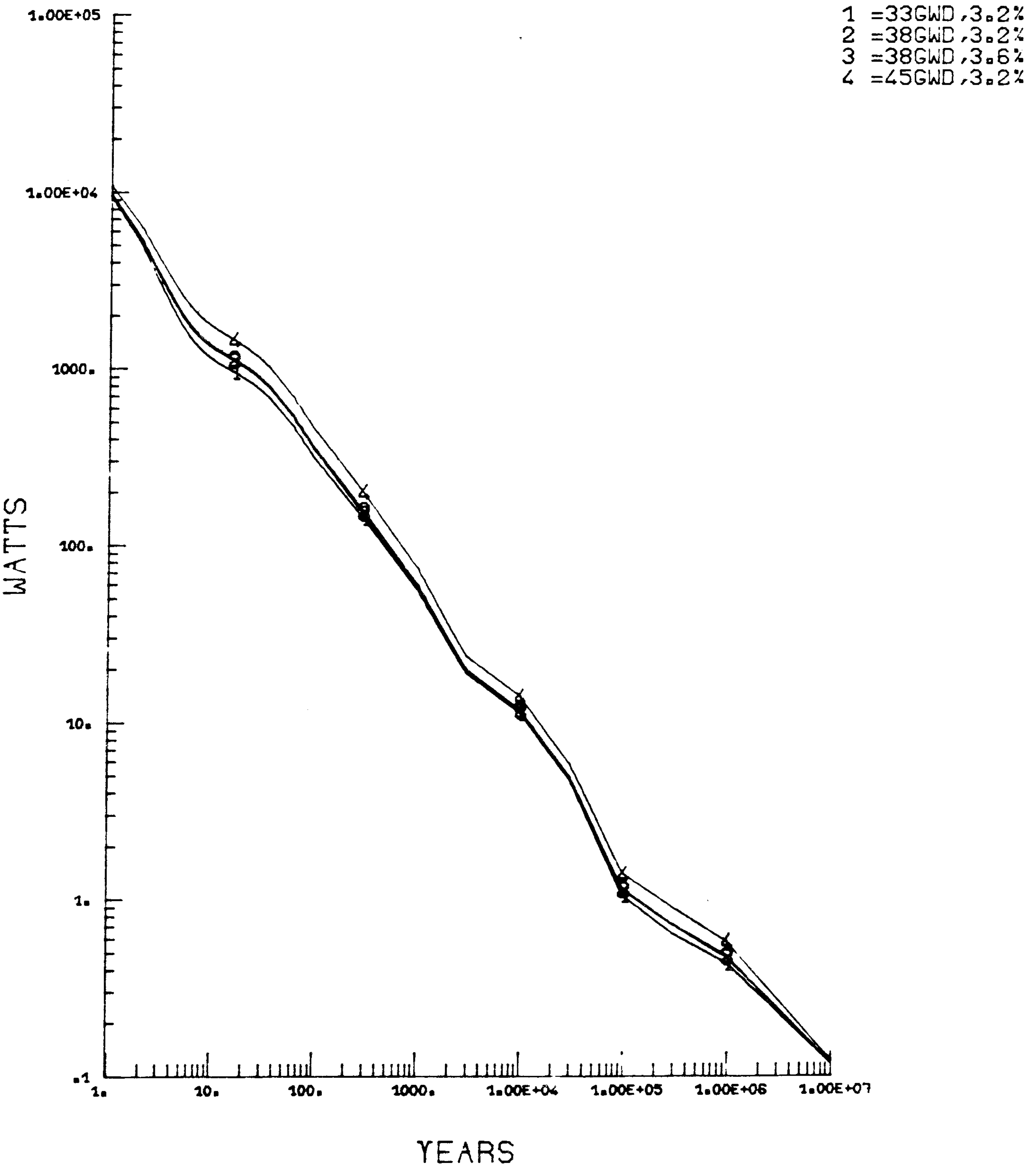

FIG 3

CALCULATION OF CORE INVENTORY

REACTOR TYPE PWR
SPECIFIC POWER 38.5 W/G

NEUTRON EMISSION(TOTAL)

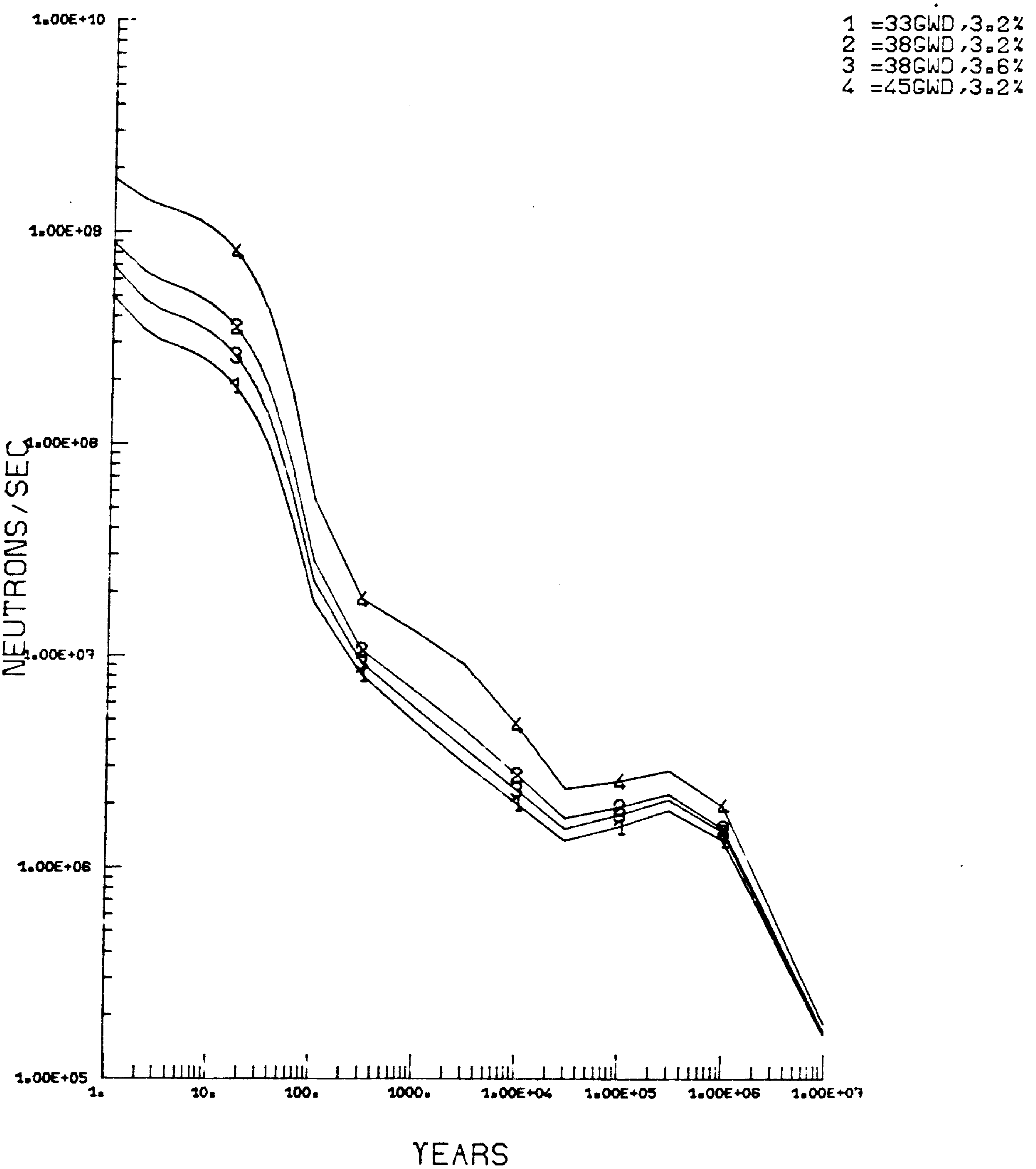

FIG 4

CALCULATION OF CORE INVENTORY

REACTOR TYPE BWR
SPECIFIC POWER 22.0 W/G

RADIOACTIVITY(TOTAL)

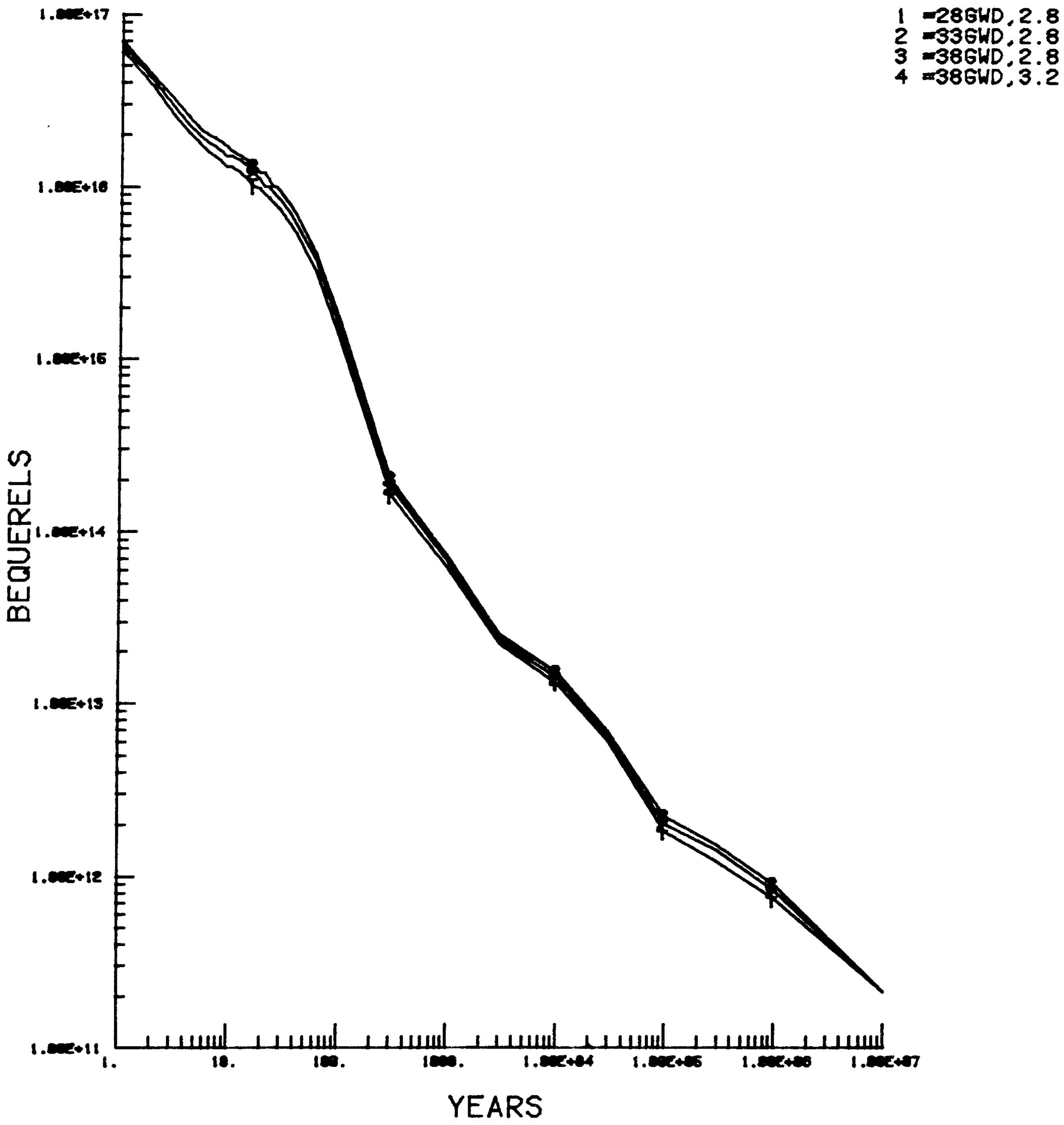

FIG 5

CALCULATION OF CORE INVENTORY

REACTOR TYPE BWR
SPECIFIC POWER 22.0 W/G

RADIOACTIVITY(ALFA)

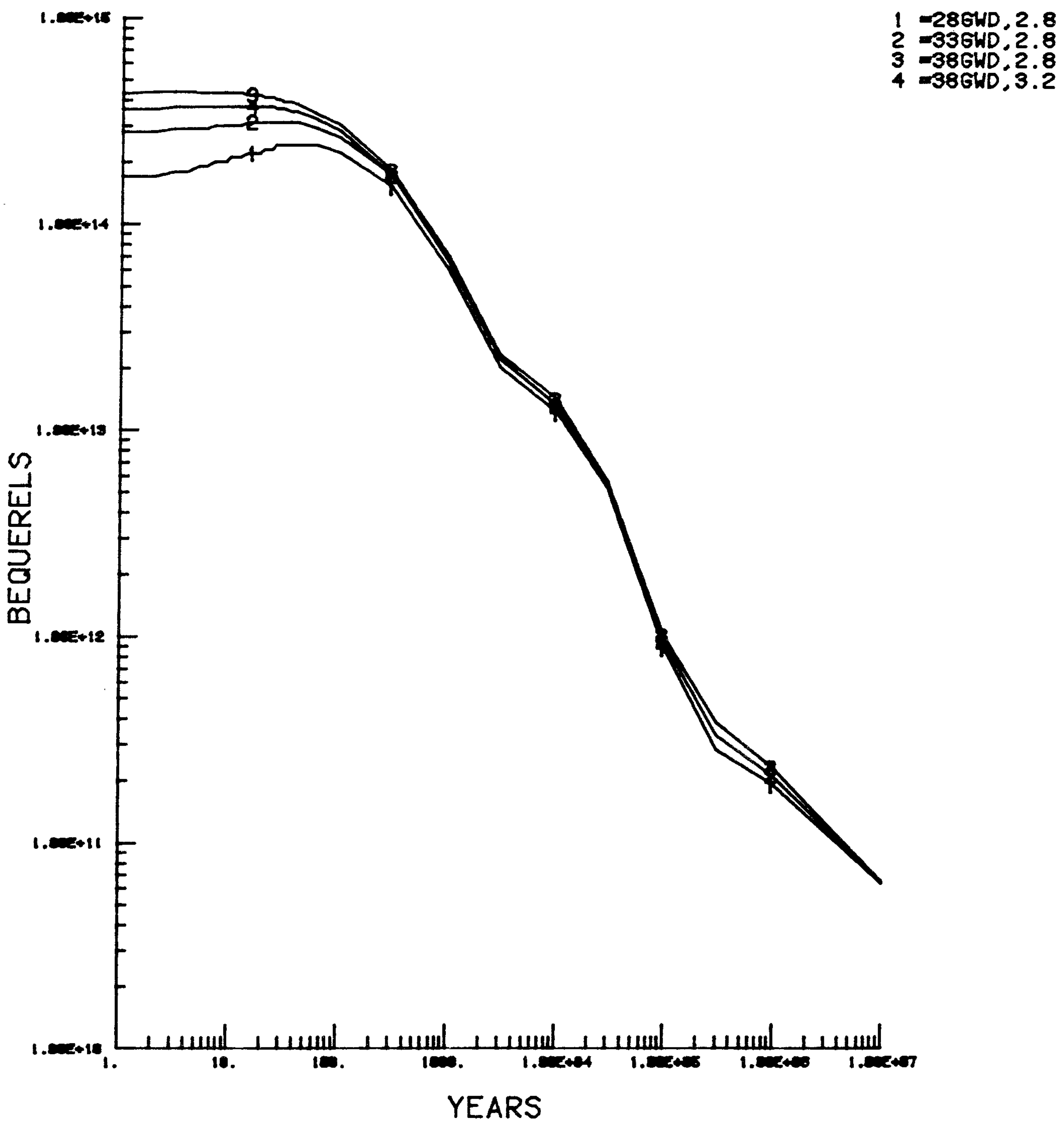

FIG 6

CALCULATION OF CORE INVENTORY

REACTOR TYPE BWR
SPECIFIC POWER 22 W/G

THERMAL POWER(TOTAL)

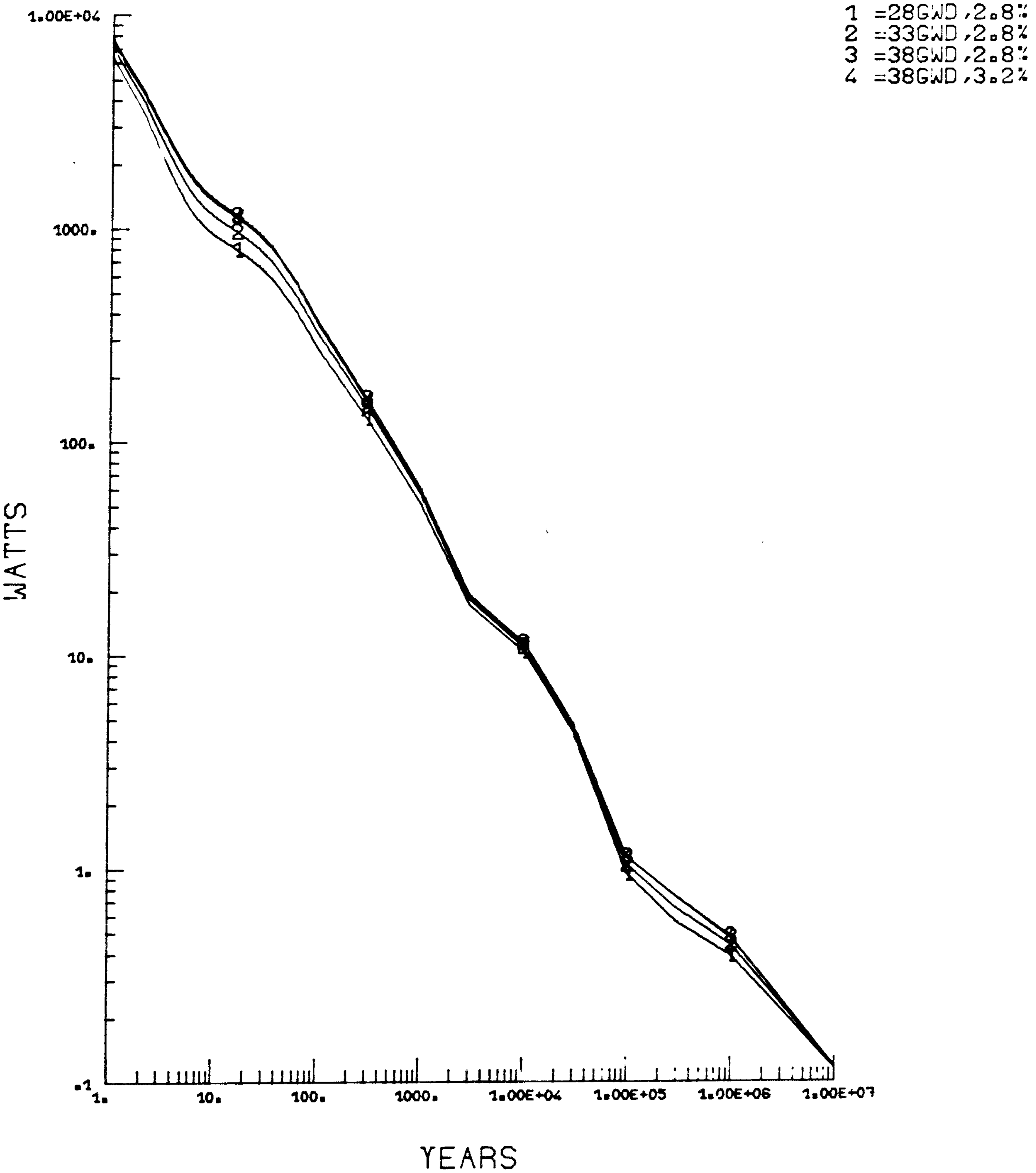

FIG 7

CALCULATION OF CORE INVENTORY

REACTOR TYPE BWR
SPECIFIC POWER 22 W/G

NEUTRON EMISSION(TOTAL)

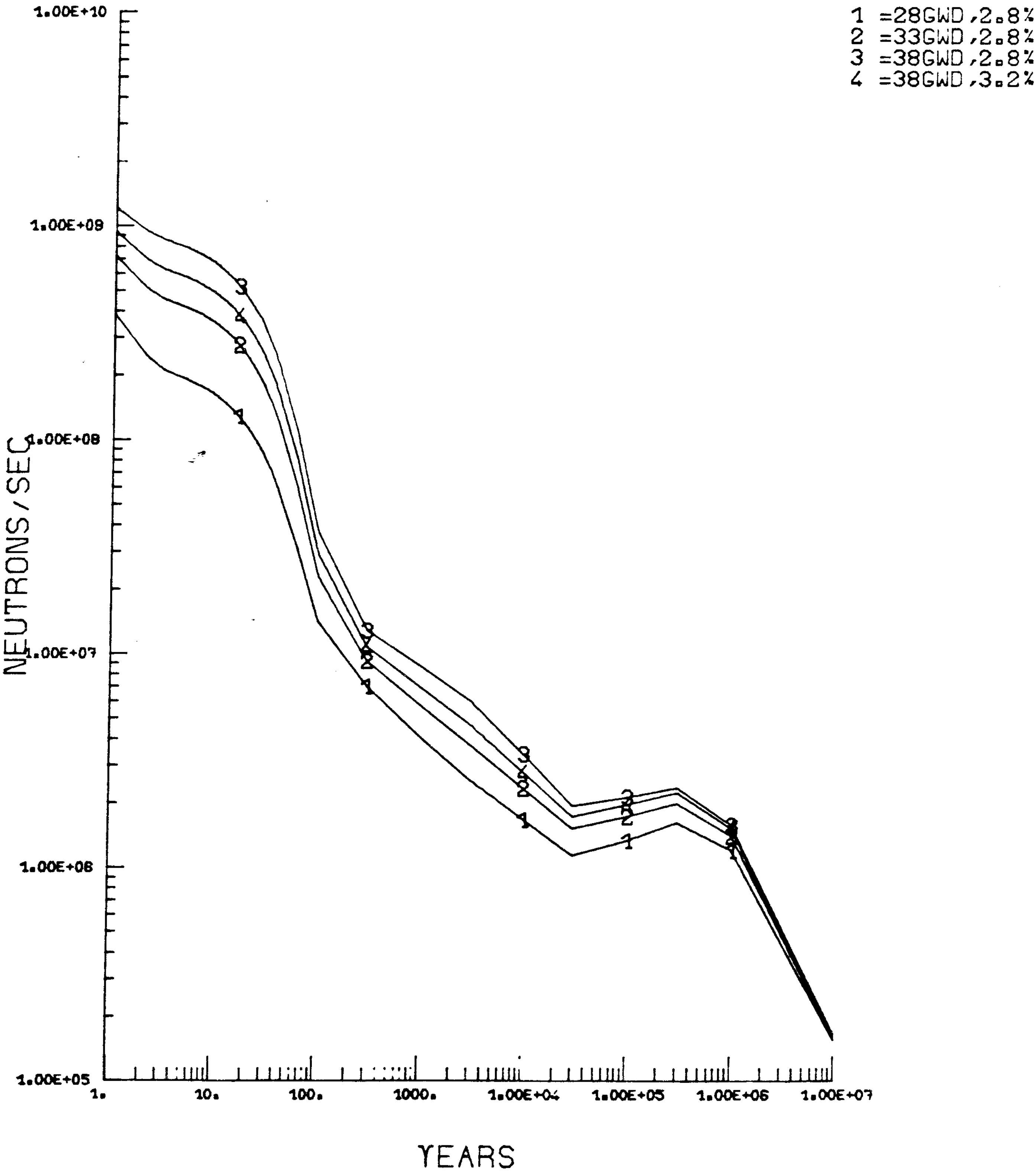

FIG 8

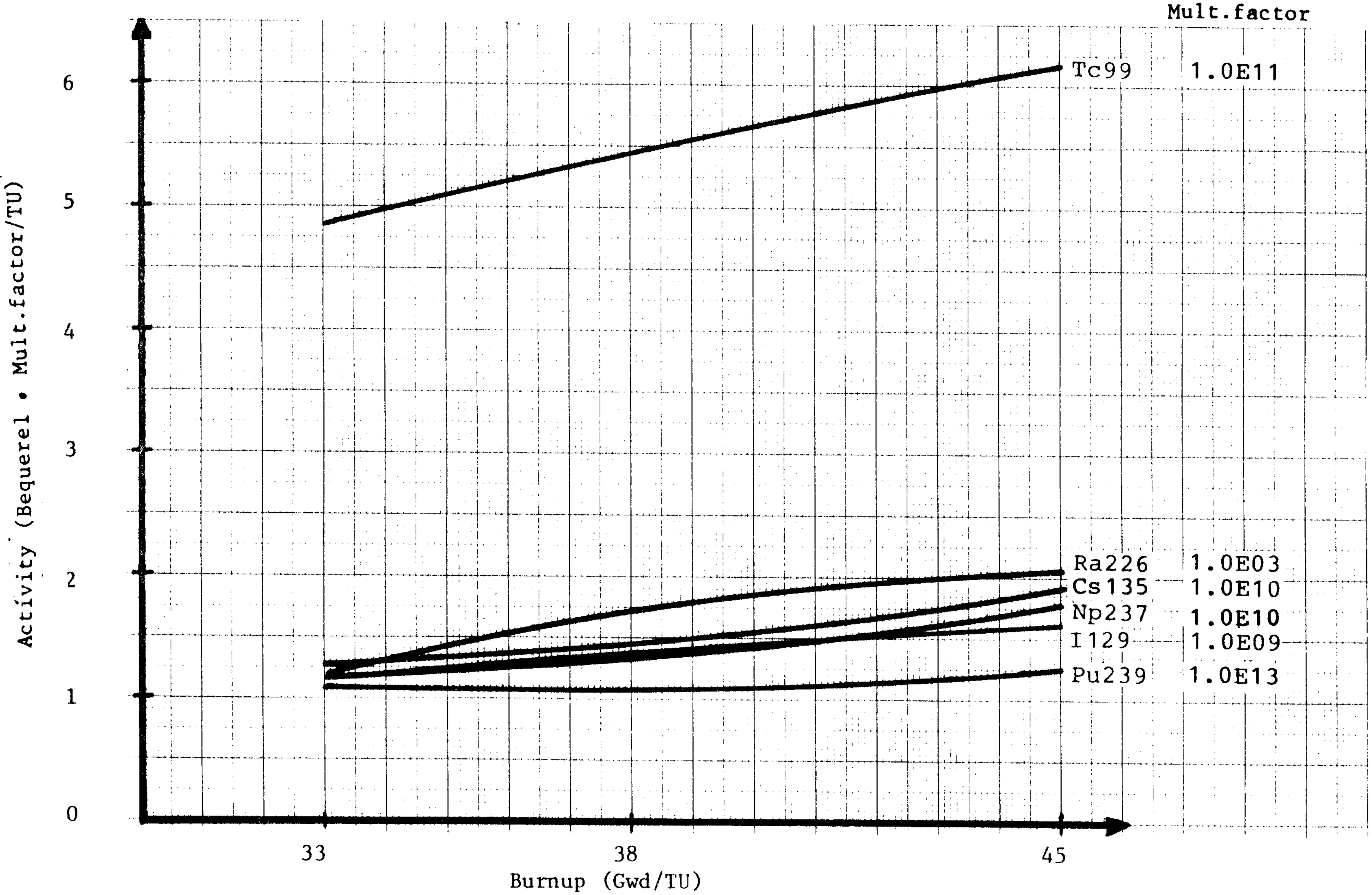

Fig 9. The activity as a function of the burnup for some important nuclides in the nuclear fuel of a PWR. Enrichment: 3.2 %.

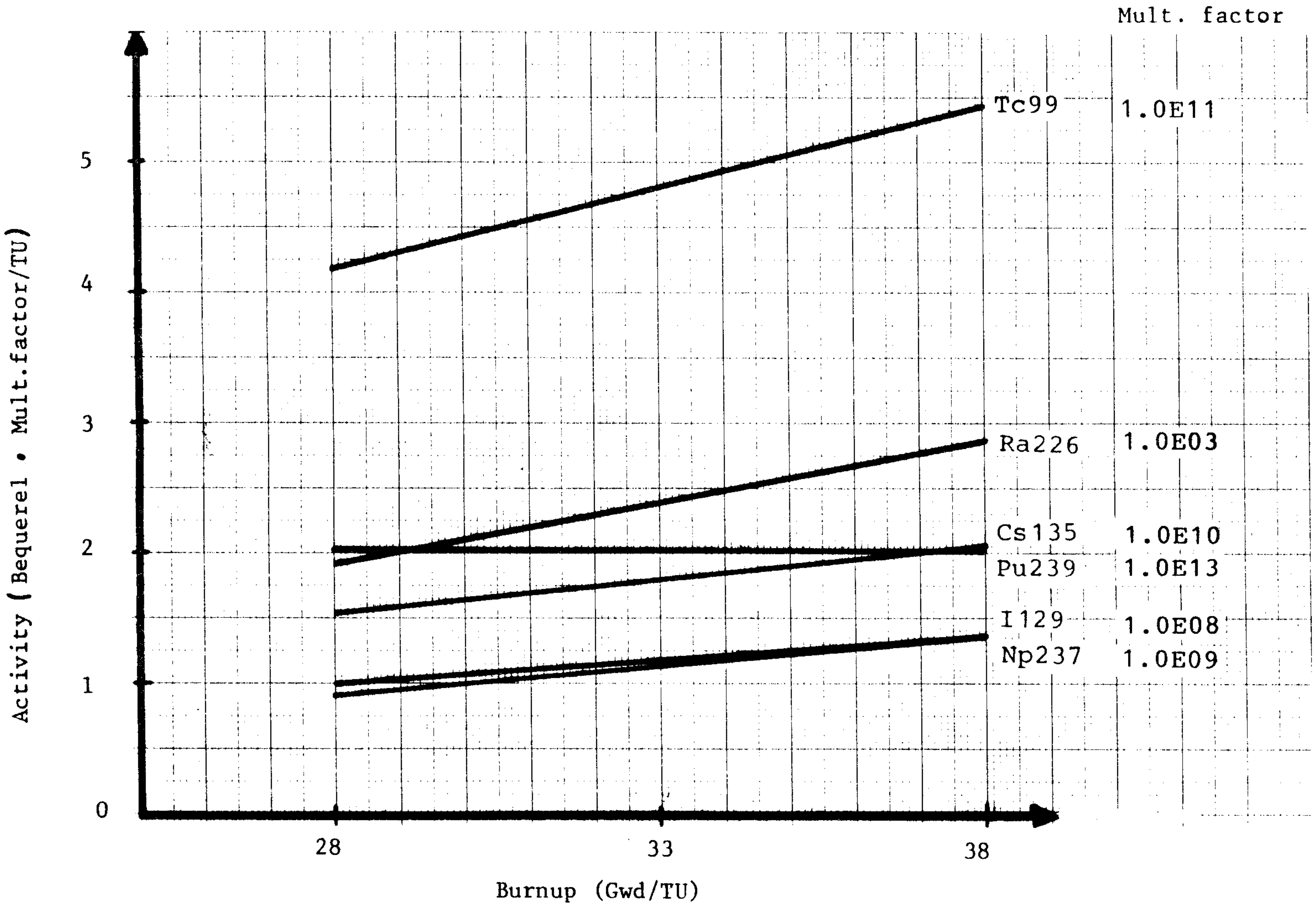

Fig 10. The activity as a function of the burnup for some important nuclides in the nuclear fuel of a BWR. Enrichment 2.8 %.

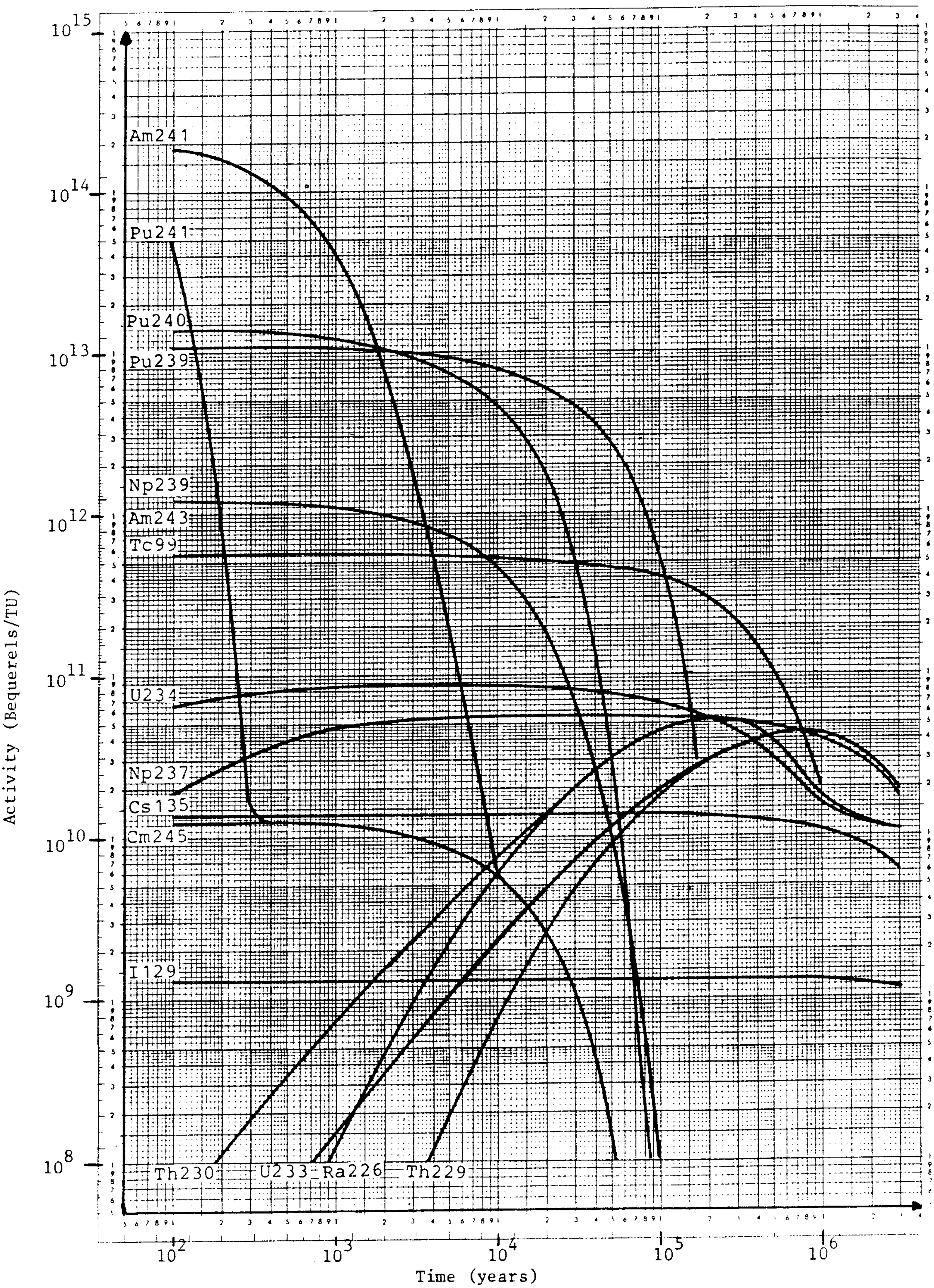

Fig 11. The activity for the most important nuclides as a function of the time after discharge for a PWR nuclear fuel after burnup of 38 Gwd/TU

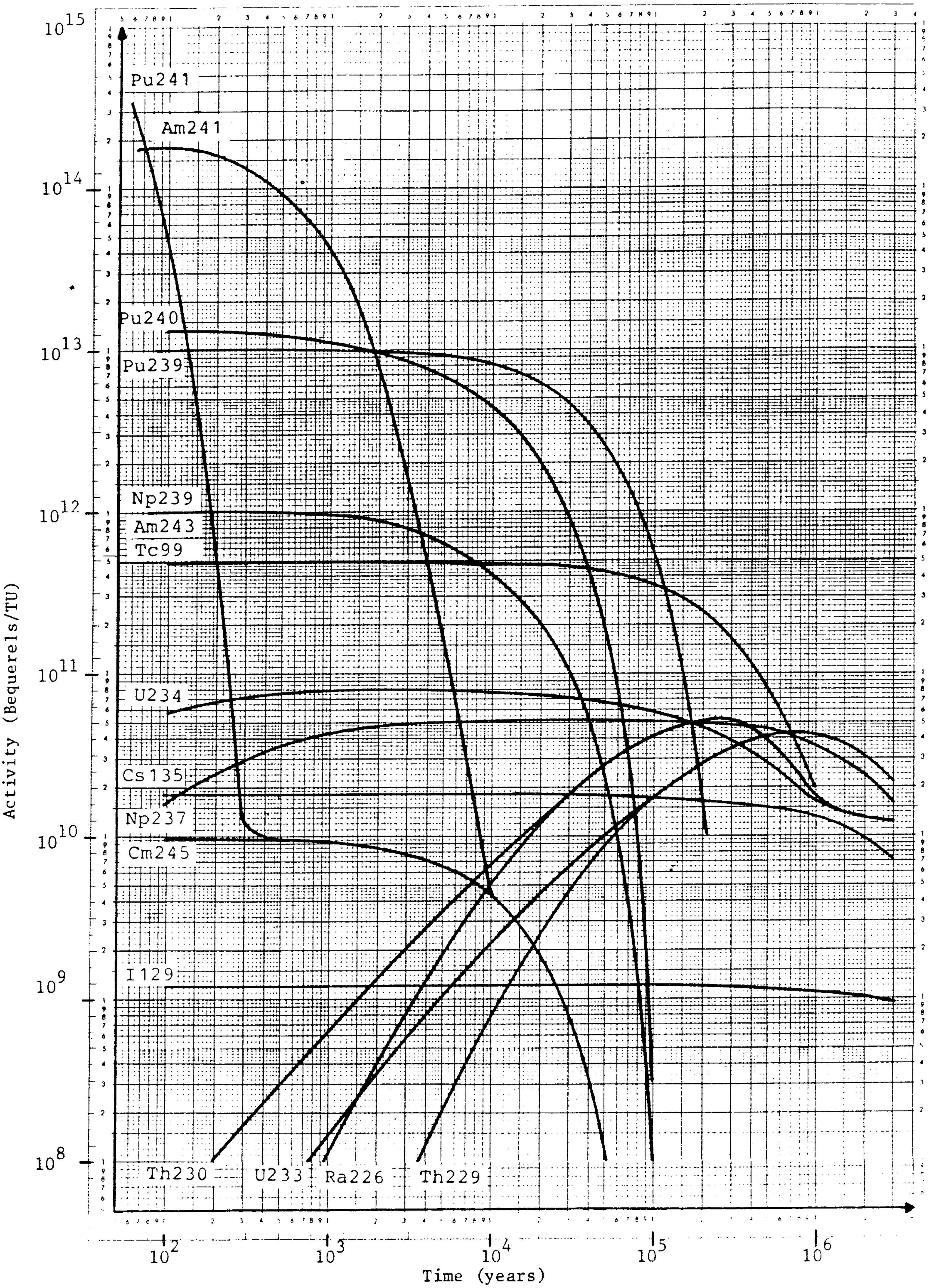

Fig 12. The activity for the most important nuclides as a function of the time after discharge for a BWR nuclear fuel after burnup of 33 Gwd/TU

LIST OF KBS's TECHNICAL REPORTS

1977-78

TR 121 KBS Technical Reports 1 - 120.
Summaries. Stockholm, May 1979.

1979

TR 79-28 The KBS Annual Report 1979.
KBS Technical Reports 79-01--79-27.
Summaries. Stockholm, March 1980.

1980

TR 80-26 The KBS Annual Report 1980.
KBS Technical Reports 80-01--80-25.
Summaries. Stockholm, March 1981.

1981

TR 81-17 The KBS Annual Report 1981.
KBS Technical Reports 81-01--81-16
Summaries. Stockholm, April 1982.

1983

TR 83-01 Radionuclide transport in a single fissure
A laboratory study
Trygve E Eriksen
Department of Nuclear Chemistry
The Royal Institute of Technology
Stockholm, Sweden 1983-01-19

TR 83-02 The possible effects of alfa and beta radiolysis
on the matrix dissolution of spent nuclear fuel
I Grenthe
I Puigdomènech
J Bruno
Department of Inorganic Chemistry
Royal Institute of Technology
Stockholm, Sweden January 1983

TR 83-03 Smectite alteration
Proceedings of a colloquium at State University of New York at Buffalo, May 26-27, 1982
Compiled by Duwayne M Anderson
State University of New York at Buffalo
February 15, 1983

TR 83-04 Stability of bentonite gels in crystalline rock - Physical aspects
Roland Pusch
Division Soil Mechanics, University of Luleå
Luleå, Sweden, 1983-02-20

TR 83-05 Studies of pitting corrosion on archeological bronzes
Åke Bresle
Jozef Saers
Birgit Arrhenius
Archeological Research Laboratory
University of Stockholm
Stockholm, Sweden 1983-02-10

TR 83-06 Investigation of the stress corrosion cracking of pure copper
L A Benjamin
D Hardie
R N Parkins
University of Newcastle upon Tyne
Department of Metallurgy and Engineering Materials
Newcastle upon Tyne, Great Britain, April 1983

TR 83-07 Sorption of radionuclides on geologic media - A literature survey. I: Fission Products
K Andersson
B Allard
Department of Nuclear Chemistry
Chalmers University of Technology
Göteborg, Sweden 1983-01-31

TR 83-08 Formation and properties of actinide colloids
U Olofsson
B Allard
M Bengtsson
B Torstenfelt
K Andersson
Department of Nuclear Chemistry
Chalmers University of Technology
Göteborg, Sweden 1983-01-30

TR 83-09 Complexes of actinides with naturally occurring organic substances - Literature survey
U Olofsson
B Allard
Department of Nucluear Chemistry
Chalmers University of Technology
Göteborg, Sweden 1983-02-15

TR 83-10 Radiolysis in nature: Evidence from the Oklo natural reactors
David B Curtis
Alexander J Gancarz
New Mexico, USA February 1983

TR 83-11 Description of recipient areas related to final storage of unreprocessed spent nuclear fuel
Björn Sundblad
Ulla Bergström
Studsvik Energiteknik AB
Nyköping, Sweden 1983-02-07

TR 83-12 Calculation of activity content and related properties in PWR and BWR fuel using ORIGEN 2
Ove Edlund
Studsvik Energiteknik AB
Nyköping, Sweden 1983-03-07