I.D. #77-11-07

18 (4)

RELATIVE SPENT FUEL STORAGE HAZARD

Prepared for the

AMERICAN NUCLEAR SOCIETY
WINTER MEETING
SAN FRANCISCO, CALIFORNIA

by

James F. Strahl, NUS Corporation*
Daniel F. Brosnan, Los Angeles Department of Water & Power
Eugene N. Cramer, Southe-- California Edison Company

November 30, 1977

*NUS CORPORATION
4 Research Place
Rockville, Maryland 20850
Telephone: 301-948-7010

8007140 051

5. Relative Spent Fuel Pool Hazard, *James F. Strahl (NUS), Dan Brosnan (LADWP), E. N. Cramer (So. Cal Ed)*

The unsettled nature of nuclear reactor waste disposal plans led utilities to increase[1] the storage capability of their spent fuel pools; increasing from about 1⅓ cores to about 3⅔ cores. While still maintaining capability of a full-core discharge, this would increase the actual storage from a single yea[illegible] to as much as 10 years.

Following the P[illegible]ent's (Nuclear) Energy Messages of April 1977, the [illegible]ibility exists that interim surface storage may be required for longer periods—either in a centralized facility yet to be built, or by further increasing storage capability in already built pools at the existing reactors. Quite aside from the political and licensing questions, it appears appropriate to examine the relative technical hazard resultant from letting the fuel elements accumulate in the spent fuel pool; i.e., no shipment to other facilities.

Figure 1 gives a first approximation answer to this technical question for a nominal 1300-MW(e) PWR. The Ingestion Toxicity Index option of computer program ORIGEN was used as an indicator of relative hazard, assuming that an annual transfer of one-third of the core to the spent fuel pool was instantaneously accomplished on the tenth day after shutdown in all cases.

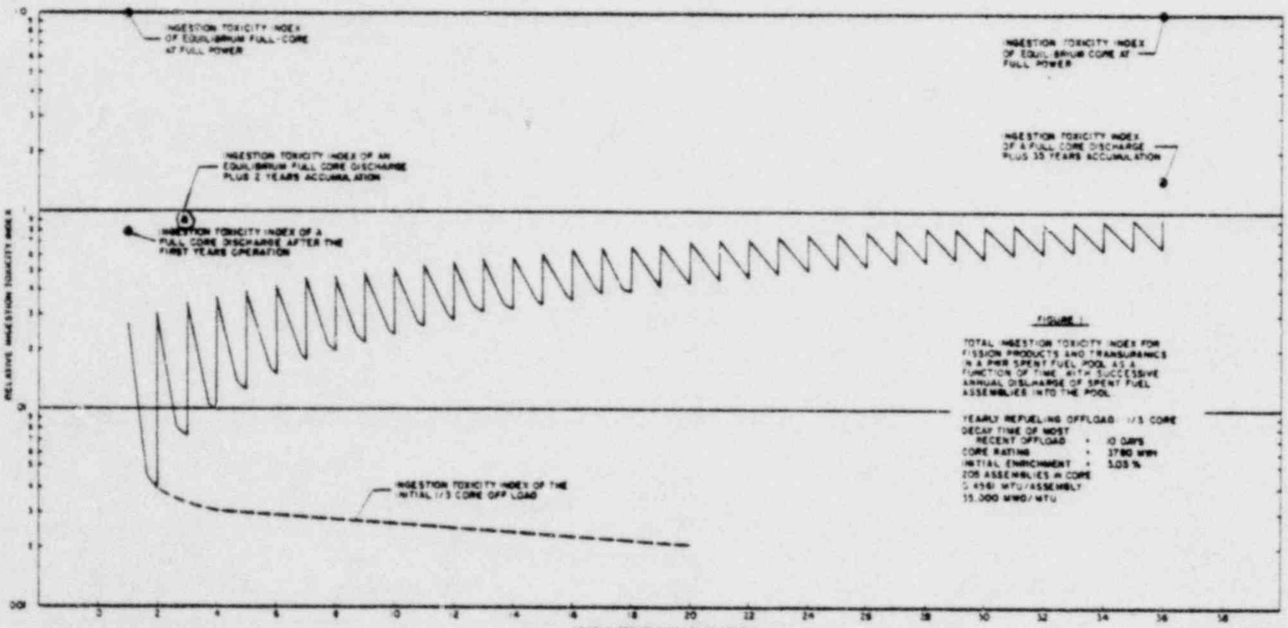


Fig. 1.

The results indicate:

1. At all times, the toxicity indicator for 36 years' accumulation remains well below that of the full core at the instant of reactor shutdown.

2. Only after about 25 years of accumulation would a one-third-core discharge equal the toxicity indicator of a full-core discharge at the end of the full year.

3. If the unit were to be operated for an arbitrary 35 years with annual refueling and then the full core discharged, the toxicity indicator would be only 75% more than that for a full-core discharge at the end of the first year's operation.

Two further notes:

1. In a licensing situation, radioactivity from noble gases may be the controlling situation. By curie content, the noble gases krypton and xenon in a fuel element are about 1% of the total curie content for the times of interest.

2. The use of an Ingestion Toxicity Index is only[2] to give perspective "without performing a comprehensive risk analysis. A convenient basis for this is the use of toxicity indices, i.e., dilution by water to meet public drinking standards. . .This does not take into account waste forms and solubility, storage facility design, remoteness from man's environment, or food chain buildup. Moreover, there appears to be no way to assign an absolute value to the levels of toxicity represented in this manner and the results are easily misinterpreted by those who do so."

Even given these caveats, it would appear that there should not be undue concern about accumulation of spent fuel assemblies at nuclear reactors properly designed to control the hazard of a full-core discharge.

---

1. See *Trans. Am. Nucl. Soc.*, 26, pp. 253-262 (June 1977); at a Special Session on Spent Fuel Storage, eight papers addressed the design of increased storage capability at the LWR.

2. R. M. FLEISCHMAN and R. C. LIIKALA, "Isotopic Composition and Radiological Properties of Uranium in Selected Fuel Cycles," BNWL-SA-5375; ERDA Conf. Occupational Health Experience with Uranium (Apr. 28, 1975).

VOLUME 27
TANSAO 27 1-1028 (1977)
ISSN: 0003-018X

TRANSACTIONS

OF THE AMERICAN NUCLEAR SOCIETY

1977 WINTER MEETING

The San Francisco Hilton & Tower Nov. 27-Dec. 2, 1977 • San Francisco, California

---

I.D. #77-11-07

RELATIVE SPENT FUEL STORAGE HAZARD

Prepared for the

AMERICAN NUCLEAR SOCIETY
WINTER MEETING
SAN FRANCISCO, CALIFORNIA

by

James F. Strahl, NUS Corporation*
Daniel F. Brosnan, Los Angeles Department of Water & Power
Eugene N. Cramer, Southern California Edison Company

November 30, 1977

*NUS CORPORATION
4 Research Place
Rockville, Maryland 20850
Telephone: 301-948-7010

TABLE OF CONTENTS

ACKNOWLEDGMENT

The authors are indebted to Ms. Emily Chumley* who obtained and analyzed much of the nuclear data presented herein, and Miss Julie Reinhold, who prepared this paper.

---

* Present address: 717 Lake Forest Drive, Vicksburg, Mississippi

LIST OF TABLES AND FIGURES

1. INTRODUCTION AND SUMMARY

The unsettled nature of the nuclear waste disposal plans in the United States has led utilities and industry to reevaluate the potential impact on all phases of the fuel cycle, especially as related to spent fuel discharge, including fuel storage, handling, and transportation. Following the President's (Nuclear) Energy message of April, 1977, it became evident that interim surface storage of spent fuel assemblies may be required for longer periods of time than originally anticipated. In the absence of definite commitments to additional large away-from-reactor storage facilities, several utilities have attempted to delay the shortage of storage space through spent fuel pool modification, thus effectively preventing the loss of either full core discharge capability or recycle discharge capability for several additional years (see Reference 1).

The utilities actions to modify pools to accommodate several additional cycles (or batches) of spent fuel has resulted in the generation of several questions associated with technical, political, and licensing issues. Aside from the political and licensing issues, several technical problems associated with anticipated fission and actinide product buildup, decay, cleanup, biological dose rates, and heat generation have been encountered.

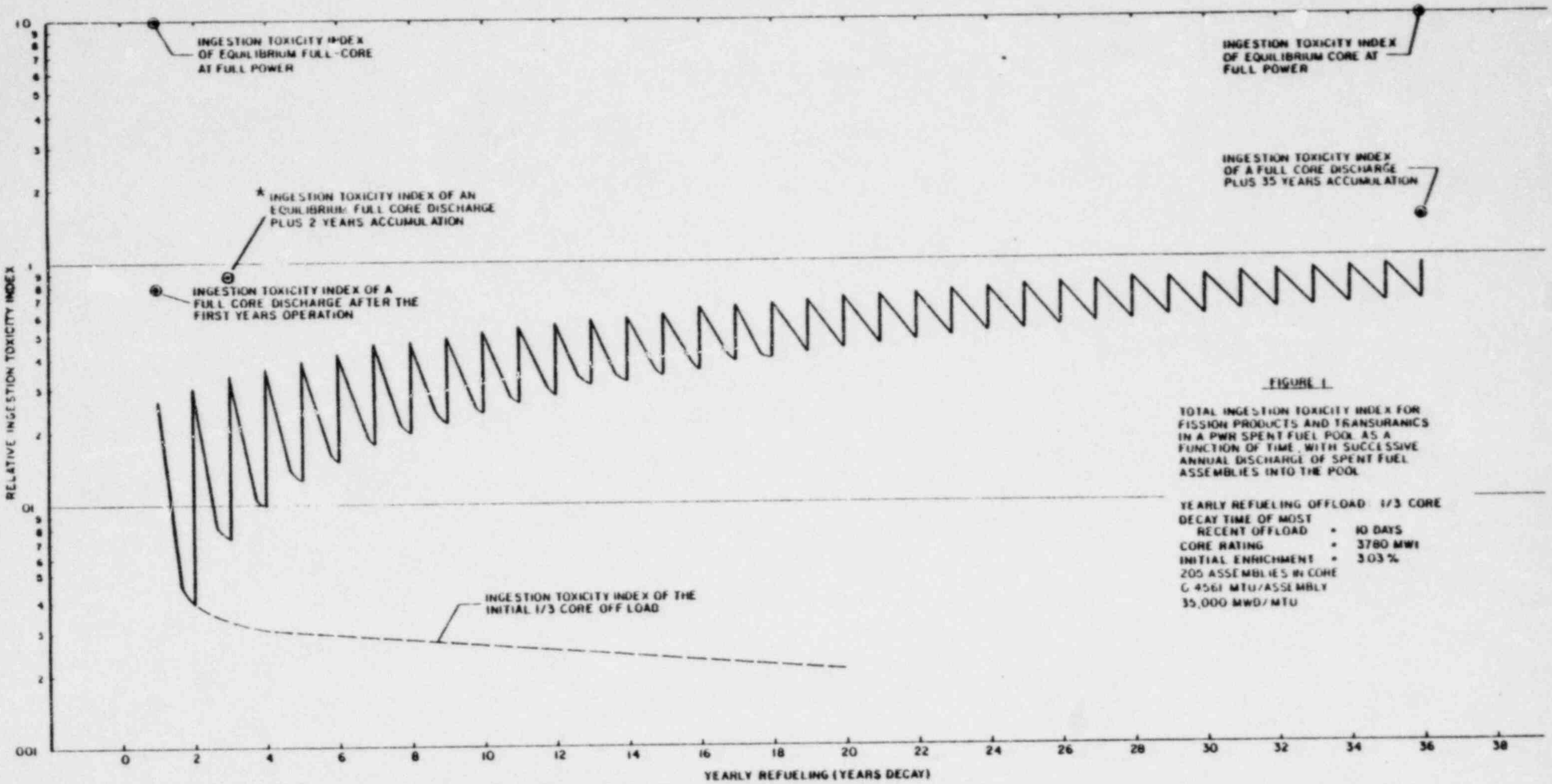
The purpose of this paper is to define the relative technical hazards of fission products and actinides associated with long term accumulation of spent fuel in a LWR pool relative to that associated with a full core at the instant of shutdown, and further to define the long term accumulation hazards numerically in terms of Ingestion Toxicity Indices (ITI, in cubic meters of water) and activity (in Curies). In addition, this paper attempts to identify the significance of burnup on the growth and decay of the major isotopes contributing to the overall predicted spent fuel pool activity and ITI.

The data provided in this paper shows that:

a. Only after approximately 25 years would the spent fuel ITI associated with the accumulation of one-third core per year discharge equal the ITI of the initial full core discharge 10 days after shutdown.

b. If the unit was to be operated for an arbitrary 36 years with annual refuelings, and subsequently a full core was discharged 10 days after shutdown, the ITI of the fuel in the pool would be approximately 85% larger than the ITI associated with the initial full core discharge 10 days after shutdown.

Thus, from a hazard standpoint, it can be concluded that there should not be undue concern about the accumulation of spent fuel assemblies at nuclear reactors properly designed to control the hazards of a single equilibrium full core discharge.



* This relative ITI was not correctly plotted in Transactions.

2. METHODS OF ANALYSIS

To define the technical hazards and important factors controlling the growth of fission products and activities associated with the long term accumulation of spent fuel in a pool, several parametric analyses were performed with a point depletion code modeling a LWR spent fuel assembly, fresh batch discharge, and a full core discharge. Presented below is a discussion of the assumptions and techniques used to define the spent fuel storage hazards.

2.1 Assumptions

It should be noted that the assumptions presented below quantitatively limit the results to PWR spent fuel storage pools. However, it is not expected that the use of BWR fuel with realistic design parameters consistent with those presented below for PWR fuel would change the results or conclusions presented in this paper.

a. The fuel parameters selected for this study are consistent with a second generation PWR.

b. A reactor power of 3780 MWt was chosen to be representative of the second generation PWR.

c. All of the PWR fuel was assumed to be initially enriched to 3.03% U-235.

d. During all phases of irradiation it was assumed that the reactor core consisted of 205 fuel assemblies.

e. Each of the 205 fuel assemblies generated 0.5% (1/205) of the reactor power during its lifetime prior to discharge.

f. Each fuel assembly contained 0.4561 metric tons of uranium (MTU).

g. Only irradiation of uranium fuel was considered. Activation products associated with fuel impurities, cladding, and assembly structure were not considered.

h. Since it was assumed that each assembly generates 0.5% of the power during its lifetime, the average specific power was used over the irradiation period for all computer calculations.

i. The equilibrium core was assumed to consist of three (3) cycles with the following representative burnups* at time of discharge:

1. 1/3 core with a burnup of 35000 MWD/MTU
2. 1/3 core with a burnup of 23333 MWD/MTU
3. 1/3 core with a burnup of 11667 MWD/MTU

2.2 Hazard Model Description

To define the radioisotopic inventories in PWR spent fuel as a function of burnup and decay time, and further to evaluate the relative biological hazard of fuel stored in a spent fuel pool over a period of time as compared to a full core offload, calculations were performed to generate both fission product/actinide activities and ITI for the following fuel conditions:

a. Equilibrium burnup of one PWR reactor core.
b. Burnup of one PWR cycle (one-third of a core) to 35000 MWD/MTU.
c. Burnup of a single PWR assembly to 10000 MWD/MTU.
d. Burnup of a single PWR assembly to 35000 MWD/MTU.

The ORIGEN computer code was used for all basic calculations for the analyses categorized above (see Reference 2). ORIGEN is a versatile

* As used herein, burnup is a measure of the amount of power produced by the fuel prior to removal from the reactor. The units of burnup used in this paper are megawatt-days per metric ton of uranium (MWD/MTU).

point depletion code which solves the equations of radioactive growth and decay for a large number of isotopes with arbitrary coupling. The code uses the matrix exponential method to solve a large system of coupled, linear, first-order ordinary differential equations with constant coefficients.

The ORIGEN computer code was used to calculate the activity and ITI* in water for approximately 820 and 101 fission product and actinide isotopes, respectively. The case (a) analyses were performed to identify the fission product/actinide activity and ITI for a PWR full core, experiencing equilibrium burnup, immediately after shutdown ($t_s = 0$) and 10 days after shutdown. The case (b) analyses were performed to identify the fission product/actinide activity and ITI for one PWR fuel cycle, experiencing a burnup of 35000 MWD/MTU, for a time period between immediately after shutdown and 35 years after shutdown. The data obtained from case (b) was subsequently used to predict the activity and ITI buildup in a spent fuel pool over a 36 year operating time span per the accumulation of one PWR fuel cycle each year. These data were then used in conjunction with case (a) data to define the ITI anticipated in a spent fuel pool, with the yearly accumulation of 36 PWR fuel cycles, relative to that expected with a full core discharge immediately after shutdown. The case (c) and (d) activity and ITI analyses were performed to (1) identify the significance of burnup on the growth and decay of radionuclides in one PWR assembly, (2) define the major isotopes contributing to the overall predicted activity and ITI, and (3) aid in understanding the activity trends observed in the case (b) results.

---

* The ITI as defined herein is the volume of water required to dilute the activity of the spent fuel to levels given in Table II, column 2, of 10CFR20 (see Reference 3).

2.3 Spent Fuel Activities/Ingestion Toxicity Indices

The equilibrium core ITI and activities expected at shutdown and 10 days after shutdown (case (a)) are defined in Table 1. This information was obtained directly from the ORIGEN computer output. Results of the ORIGEN computer calculations performed to satisfy case (b) are summarized in Tables 2 and 3, which identify the ITI and activity, respectively, for a typical PWR fuel cycle experiencing a burnup of 35000 MWD/MTU. These tables define the respective ITI and activities for both fission products and the actinides, and further identifies these data as a function of decay time (i.e., length of time discharged from the reactor).

Data from Tables 2 and 3 were used to define the growth of spent fuel pool ITI and activities with the accumulation of one spent fuel cycle per year over a 36 year operating time period. Results of these calculations are defined in Table 4. Note that the column designated "Prior to Most Recent Offload" defines the total residual ITI and activity contained in all the fuel cycles located in the pool immediately prior to the addition of a freshly discharged cycle, therefore identifying the extent of radionuclide decay between cycle offloads.

The single assembly ITI and activity expected as a function of decay time (cases (c) and (d)) is defined in Tables 5 and 6, respectively. These tables identify the fission product, actinide, and total ITI and activity for an assembly experiencing burnups of 10000 and 35000 MWD/MTU. Review of the ORIGEN generated isotopic data for the 35000 MWD/MTU assembly burnup case shows that, after one day of decay, the most significant actinide contributors to the ITI are Neptunium 238 and 239 (ITI = 9.4×10^{10}) and Uranium 237 (ITI = 4.82×10^{9}), while the most significant fission product contributors to the ITI are Iodine 131 through 135 (ITI = 2.16×10^{12}) and Strontium 89 through 91 (ITI = 2.56×10^{11}). After 20 years of decay, the most significant actinide contributors to the ITI are Plutonium 238 through 241 (ITI = 4.48×10^{8}), Americium 241 (ITI = 2.82×10^{8}) and Curium 244 (ITI = 1.26×10^{8}), while the most significant fission product contributor to the ITI is Strontium 90 (ITI = 7.42×10^{10}).

3. RESULTS

The ITI data present in Section 2 was generated specifically to identify the spent fuel pool hazards with the accumulation of fuel relative to that of a full core immediately subsequent to shutdown, and further to define the parameters controlling the growth rate of the pool ITI. Thus, care should be exercised in the interpretation of the data presented above, since a literal translation of the magnitudes would imply that all the spent fuel would be available for dispersion in water. In reality most of the fuel would not reach the general population or unrestricted areas, since several secondary defenses exist between the fuel and site boundary, such as fuel cladding, spent fuel pool water and structure, slow migration through and high filtration in surrounding soil, and additional dilution of the radionuclides. To explain in the terms of Reference 4, the use of an ITI is only to give perspective "without performing a comprehensive risk analysis. A convenient basis for this is the use of toxicity indices, i.e., dilution by water to meet public drinking standards . . . This does not take into account waste forms and solubility, storage facility design, remoteness from man's environment, or food chain buildup. Moreover, there appears to be no way to assign an absolute value to the levels of toxicity represented in this manner and the results are easily misinterpreted by those who do so."

To define the spent fuel pool relative hazards, ITI data from Table 4 was normalized to the equilibrium core ITI data (at the instant of reactor shutdown) defined in Table 1. Those normalized results are shown in Figure 1. It should be noted that these data incorporate the condition that instantaneous transfer of one-third of a core is accomplished on the tenth day after shutdown. The results of Figure 1 indicate the following:

a. At all times, the ITI associated with 35 years accumulation of spent fuel in the pool is much less than that of a full core at the instant of shutdown.

b. Only after approximately 25 years would the spent fuel ITI associated with the accumulation of one-third core per year discharge equal the ITI of the initial full core discharge 10 days after shutdown.

c. If the unit was to be operated for an arbitrary 36 years with annual refuelings, and subsequently a full core was discharged 10 days after shutdown, the ITI of the fuel in the pool would be approximately 85% larger than the ITI associated with the full core discharge 10 days after shutdown.

d. The ITI associated with 2 years of annual refuelings and a full core discharge is approximately 9% larger than that associated with the initial full core discharge.

The sawtooth nature of the curve shown in Figure 1 is due to the law of radionuclide decay. Figure 2 shows the basis for this process, being a representation of the ITI for a single PWR fuel element placed in the spent fuel pool after one and three years of full power operation. Note that approximately 1% of the fuel element toxicity remains after one year of decay, at which time 65% of the ITI is contributed by Strontium 90, 14% by Cerium 144, 0.3% by Plutonium 238 and 241, and 0.24% by Curium 242 and 244. The gradual accumulation of longer half-life isotopes in the pool is shown in Figure 1 by the slow increase in the minimum occuring immediately prior to a refueling discharge.

As discussed in Section 2, the ITI represents an idealized situation, perhaps equivalent to a perfect blending of the spent fuel contents and water. Since it is unlikely that such a situation would actually occur, a study was performed to identify the activity trends of the two noble gases Xenon and Krypton as compared to the total activity contained in a PWR fuel assembly experiencing a burnup of 35000 MWD/MTU. Results of the comparison are shown in Figure 3. These data indicate that the activity of the more mobile noble es rapidly become less than 1% of the total activity in the fuel assembly at any given time of interest. Note that no credit has been taken for the gases which would not be released in the accident situation (i.e., retained in the fuel element).

Figures 1 through 3 utilized a logarithmic scale to compensate for the initial rapid drop-in radioactivity, so that activities over a long time period could be meaningfully displayed. Unfortunately, this does not properly portray the rapid dropoff in radioactivity. Figure 4 displays the rapid fall off of the relative activity in the spent fuel pool resulting from the successive discharge of the first two 1/3-cores of spent fuel assemblies. At 10 days after shutdown only about 6% of the gaseous activity remains, while at 100 days only 0.07% of the gaseous activity remains. The facts illustrated by Figure 4 show that most of the hazard from gaseous radioactivity in spent fuel has disappeared after several hundred days decay; with subsequent additions to the spent fuel pool, the newest batch of spent fuel assemblies is always the controlling item.

Thus, from a hazard standpoint, it can be concluded that there should not be undue concern about the accumulation of spent fuel assemblies at nuclear reactors properly designed to control the hazards of a single equilibrium full core discharge.

4. REFERENCES

1. See ANS Transactions V26, Pages 253-262, June 1977. At a Special Session on Spent Fuel Storage, eight papers addressed the design of increased storage capability at the LWR.

2. Bell, M.J., "ORIGEN - The ORNL Isotope Generation and Depletion Code," ORNL-4628, Oak Ridge National Laboratory (May 1973). ORIGEN is computer code package CCC-217 at the Radiation Shielding Information Center (RSIC) at Oak Ridge.

3. Code of Federal Regulations, Title 10, Energy, Part 20, "Standards for Protection Against Radiation," published by the Office of the Federal Register, 1976.

4. Fleischman, R.M., and Liikala, R.C., "Isotopic Composition and Radiological Properties of Uranium in Selected Fuel Cycles", BNWL-SA-5375, presented April 28, 1975 at an ERDA Conference on Occupational Health Experience with Uranium.

TABLE 1

EQUILIBRIUM CORE INGESTION TOXICITY INDICES AND ACTIVITIES

Nuclide Category	Ingestion Toxicity Index, Cubic Meters of Water		Activity, Curies	
	Shutdown	10 Days after Shutdown	Shutdown	10 Days after Shutdown
Fission Products	3.20 + 15[(1)]	2.50 + 14	1.81 + 10	1.95 + 9
Actinides	2.52 + 13	1.64 + 12	4.65 + 9	1.58 + 9
Total	3.23 + 15	2.52 + 14	2.28 + 10	3.53 + 9

(1) 3.20 + 15 = 3.20×10^{15}

TABLE 2

INGESTION TOXICITY INDEX IN ONE-THIRD CORE OFFLOAD WITH 35000 MWD/MTU BURNUP

Decay Time, Years	One-Third Core Ingestion Toxicity Index, Cubic Meters of Water		
	Actinides	Fission Products	Total
0 (1)	6.98 + 11 (2)	8.61 + 13	8.68 + 13
1	7.67 + 10	1.24 + 13	1.25 + 13
2	6.67 + 10	1.01 + 13	1.02 + 13
3	6.43 + 10	9.02 + 12	9.08 + 12
4	6.36 + 10	8.37 + 12	8.43 + 12
5	6.33 + 10	7.96 + 12	8.02 + 12
6	6.29 + 10	7.65 + 12	7.71 + 12
7	6.27 + 10	7.40 + 12	7.46 + 12
8	6.24 + 10	7.18 + 12	7.24 + 12
9	6.21 + 10	6.98 + 12	7.04 + 12
10	6.18 + 10	6.79 + 12	6.85 + 12
11	6.15 + 10	6.61 + 12	6.67 + 12
12	6.12 + 10	6.45 + 12	6.51 + 12
13	6.09 + 10	6.28 + 12	6.34 + 12
14	6.07 + 10	6.13 + 12	6.19 + 12
15	6.04 + 10	5.98 + 12	6.04 + 12
16	6.01 + 10	5.83 + 12	5.89 + 12
17	5.98 + 10	5.68 + 12	5.74 + 12
18	5.95 + 10	5.55 + 12	5.61 + 12
19	5.93 + 10	5.41 + 12	5.47 + 12
20	5.90 + 10	5.28 + 12	5.34 + 12
21	5.87 + 10	5.15 + 12	5.21 + 12
22	5.85 + 10	5.02 + 12	5.08 + 12
23	5.82 + 10	4.90 + 12	4.96 + 12
24	5.79 + 10	4.78 + 12	4.84 + 12
25	5.77 + 10	4.66 + 12	4.72 + 12
26	5.74 + 10	4.55 + 12	4.61 + 12
27	5.71 + 10	4.44 + 12	4.50 + 12
28	5.69 + 10	4.33 + 12	4.39 + 12
29	5.66 + 10	4.23 + 12	4.29 + 12
30	5.64 + 10	4.12 + 12	4.18 + 12
31	5.61 + 10	4.02 + 12	4.08 + 12
32	5.59 + 10	3.92 + 12	3.98 + 12
33	5.56 + 10	3.83 + 12	3.89 + 12
34	5.54 + 10	3.74 + 12	3.80 + 12
35	5.52 + 10	3.65 + 12	3.71 + 12

(1) Actual decay time for this cycle is zero (0) years, 10 days

(2) 6.98 + 11 = 6.98×10^{11}

TABLE 3

ACTIVITY IN ONE-THIRD CORE OFFLOAD
WITH 35000 MWD/MTU BURNUP

Decay Time, Years	One-Third Core Activity, Curies		
	Actinides	Fission Products	Total
0(1)	6.21 + 7(2)	6.79 + 8	7.41 + 8
1	4.04 + 6	8.67 + 7	9.07 + 7
2	3.68 + 6	4.61 + 7	4.98 + 7
3	3.49 + 6	2.92 + 7	3.27 + 7
4	3.33 + 6	2.10 + 7	2.43 + 7
5	3.18 + 6	1.68 + 7	2.00 + 7
6	3.05 + 6	1.44 + 7	1.74 + 7
7	2.92 + 6	1.29 + 7	1.58 + 7
8	2.80 + 6	1.20 + 7	1.48 + 7
9	2.68 + 6	1.13 + 7	1.40 + 7
10	2.57 + 6	1.07 + 7	1.33 + 7
11	2.46 + 6	1.02 + 7	1.27 + 7
12	2.36 + 6	9.86 + 6	1.22 + 7
13	2.26 + 6	9.52 + 6	1.18 + 7
14	2.17 + 6	9.21 + 6	1.14 + 7
15	2.08 + 6	8.93 + 6	1.10 + 7
16	1.99 + 6	8.67 + 6	1.07 + 7
17	1.91 + 6	8.43 + 6	1.03 + 7
18	1.83 + 6	8.20 + 6	1.00 + 7
19	1.76 + 6	7.98 + 6	9.74 + 6
20	1.69 + 6	7.77 + 6	9.46 + 6
21	1.62 + 6	7.57 + 6	9.19 + 6
22	1.56 + 6	7.38 + 6	8.94 + 6
23	1.50 + 6	7.19 + 6	8.69 + 6
24	1.44 + 6	7.01 + 6	8.45 + 6
25	1.38 + 6	6.84 + 6	8.22 + 6
26	1.33 + 6	6.67 + 6	8.00 + 6
27	1.28 + 6	6.51 + 6	7.79 + 6
28	1.23 + 6	6.35 + 6	7.58 + 6
29	1.18 + 6	6.19 + 6	7.37 + 6
30	1.14 + 6	6.04 + 6	7.18 + 6
31	1.10 + 6	5.90 + 6	7.00 + 6
32	1.06 + 6	5.75 + 6	6.81 + 6
33	1.02 + 6	5.61 + 6	6.63 + 6
34	9.81 + 5	5.48 + 6	6.46 + 6
35	9.46 + 5	5.35 + 6	6.30 + 6

(1) Actual decay time for this cycle is zero (0) years, 10 days

(2) $6.21 + 7 = 6.21 \times 10^7$

TABLE 4

SPENT FUEL POOL INGESTION TOXICITY INDEX AND ACTIVITY WITH THE ACCUMULATION OF 36 CYCLES

Number of Cycles in the Pool	Years After Initial Discharge	Spent Fuel Pool ITI, $m^3 H_2O$		Spent Fuel Pool Activity, Curies	
		Prior to Most Recent Offload	With The Most Recent Offload	Prior to Most Recent Offload	With The Most Recent Offload
1	0 (1)	0	8.68 + 13 (2)	0	7.41 + 8
2	1	1.2[illegible] + 13	9.93 + 13	9.1 + 7	8.32 + 8
3	2	2.32 + 13	1.10 + 14	1.41 + 8	8.82 + 8
4	3	3.22 + 13	1.19 + 14	1.73 + 8	9.14 + 8
5	4	4.02 + 13	1.27 + 14	1.98 + 8	9.39 + 8
6	5	4.82 + 13	1.35 + 14	2.17 + 8	9.58 + 8
7	6	5.62 + 13	1.43 + 14	2.35 + 8	9.76 + 8
8	7	6.32 + 13	1.50 + 14	2.51 + 8	9.92 + 8
9	8	7.02 + 13	1.57 + 14	2.69 + 8	1.01 + 9
10	9	7.72 + 13	1.64 + 14	2.79 + 8	1.02 + 9
11	10	8.42 + 13	1.71 + 14	2.89 + 8	1.03 + 9
12	11	9.12 + 13	1.78 + 14	3.09 + 8	1.05 + 9
13	12	9.82 + 13	1.85 + 14	3.19 + 8	1.06 + 9
14	13	1.04 + 14	1.91 + 14	3.29 + 8	1.07 + 9
15	14	1.10 + 14	1.97 + 14	3.39 + 8	1.08 + 9
16	15	1.16 + 14	2.03 + 14	3.49 + 8	1.09 + 9
17	16	1.22 + 14	2.09 + 14	3.59 + 8	1.10 + 9
18	17	1.28 + 14	2.15 + 14	3.69 + 8	1.11 + 9
19	18	1.33 + 14	2.20 + 14	3.79 + 8	1.12 + 9
20	19	1.36 + 14	2.26 + 14	3.89 + 8	1.13 + 9
21	20	1.44 + 14	2.31 + 14	3.99 + 8	1.14 + 9
22	21	1.49 + 14	2.36 + 14	4.09 + 8	1.15 + 9
23	22	1.54 + 14	2.41 + 14	4.19 + 8	1.16 + 9
24	23	1.59 + 14	2.46 + 14	4.29 + 8	1.17 + 9
25	24	1.64 + 14	2.51 + 14	4.39 + 8	1.18 + 9
26	25	1.69 + 14	2.56 + 14	4.49 + 8	1.19 + 9
27	26	1.74 + 14	2.61 + 14	4.49 + 8	1.19 + 9
28	27	1.78 + 14	2.65 + 14	4.59 + 8	1.20 + 9
29	28	1.82 + 14	2.69 + 14	4.69 + 8	1.21 + 9
30	29	1.86 + 14	2.73 + 14	4.79 + 8	1.22 + 9
31	30	1.91 + 14	2.78 + 14	4.79 + 8	1.22 + 9
32	31	1.95 + 14	2.82 + 14	4.89 + 8	1.23 + 9
33	32	1.99 + 14	2.86 + 14	4.99 + 8	1.24 + 9
34	33	2.03 + 14	2.90 + 14	4.99 + 8	1.24 + 9
35	34	2.07 + 14	2.94 + 14	5.09 + 8	1.25 + 9
36	35	2.10 + 14	2.97 + 14	5.19 + 8	1.26 + 9

(1) Actual decay time for this cycle is zero (0) years, 10 days.

(2) $8.68 + 13 = 8.68 \times 10^{13}$

TABLE 5

PWR SPENT FUEL ASSEMBLY INGESTION TOXICITY INDEX

Decay Time, Days	Ingestion Toxicity Index, Cubic Meters of Water					
	10000 MWD/MTU Burnup			35000 MWD/MTU Burnup		
	Actinides	Fission Prod.	Total	Actinides	Fission Prod.	Total
1	7.39 + 10[(1)]	2.64 + 12	2.71 + 12	1.01 + 11	2.83 + 12	2.93 + 12
10	5.89 + 9	1.12 + 12	1.13 + 12	1.02 + 10	1.26 + 12	1.27 + 12
100	8.62 + 7	1.59 + 11	1.59 + 11	1.50 + 9	2.77 + 11	2.79 + 11
1000	8.13 + 7	4.80 + 10	4.81 + 10	9.42 + 8	1.35 + 11	1.36 + 11
1460 (4 yrs)	8.21 + 7	4.35 + 10	4.36 + 10	9.26 + 8	1.22 + 11	1.23 + 11
2190 (6 yrs)	8.34 + 7	3.99 + 10	4.00 + 10	9.16 + 8	1.12 + 11	1.13 + 11
2920 (8 yrs)	8.46 + 7	3.77 + 10	3.78 + 10	9.08 + 8	1.05 + 11	1.06 + 11
3650 (10 yrs)	8.57 + 7	3.58 + 10	3.59 + 10	9.00 + 8	9.92 + 10	1.00 + 11
5475 (15 yrs)	8.77 + 7	3.16 + 10	3.17 + 10	8.80 + 8	8.73 + 10	8.82 + 10
7300 (20 yrs)	8.92 + 7	2.79 + 10	2.80 + 10	8.60 + 8	7.71 + 10	7.80 + 10

(1) $7.39 + 10 = 7.39 \times 10^{10}$

TABLE 6

PWR SPENT FUEL ASSEMBLY ACTIVITY

Decay Time, Days	Activity, Curies					
	10000 MWD/MTU Burnup			35000 MWD/MTU Burnup		
	Actinides	Fission Prod.	Total	Actinides	Fission Prod.	Total
1	7.36 + 6[1]	1.70 + 7	2.44 + 7	9.78 + 6	1.88 + 7	2.86 + 7
10	5.85 + 5	8.58 + 6	9.17 + 6	9.09 + 5	9.94 + 6	1.08 + 7
100	6.48 + 3	2.37 + 6	2.38 + 6	6.85 + 4	3.44 + 6	3.51 + 6
1000	5.69 + 3	1.69 + 5	1.75 + 5	5.16 + 4	4.75 + 5	5.27 + 5
1460 (4 yrs)	5.38 + 3	1.03 + 5	1.08 + 5	4.86 + 4	3.07 + 5	3.56 + 5
2190 (6 yrs)	4.9[illegible] + 3	6.76 + 4	7.25 + 4	4.45 + 4	2.10 + 5	2.55 + 5
2920 (8 yrs)	4.52 + 3	5.58 + 4	6.03 + 4	4.08 + 4	1.75 + 5	2.16 + 5
3650 (10 yrs)	4.15 + 3	4.98 + 4	5.40 + 4	3.75 + 4	1.56 + 5	1.94 + 5
5475 (15 yrs)	3.37 + 3	4.14 + 4	4.48 + 4	3.03 + 4	1.30 + 5	1.60 + 5
7300 (20 yrs)	2.74 + 3	3.60 + 4	3.87 + 4	2.47 + 4	1.14 + 5	1.39 + 5

(1) 7.36 + 6 = 7.36×10^6

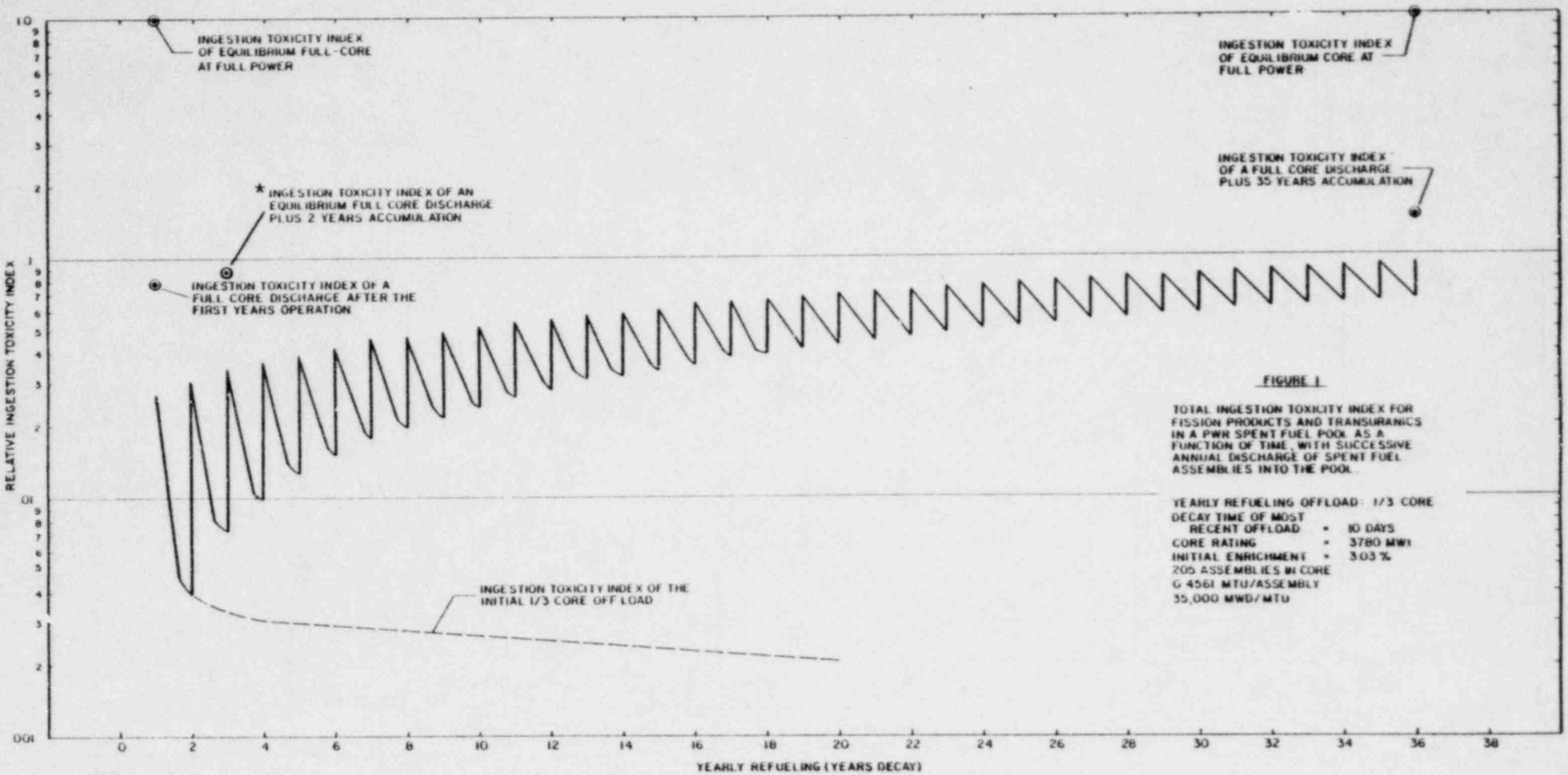


FIGURE 1

TOTAL INGESTION TOXICITY INDEX FOR FISSION PRODUCTS AND TRANSURANICS IN A PWR SPENT FUEL POOL AS A FUNCTION OF TIME, WITH SUCCESSIVE ANNUAL DISCHARGE OF SPENT FUEL ASSEMBLIES INTO THE POOL

* This relative ITI was not correctly plotted in Transactions.

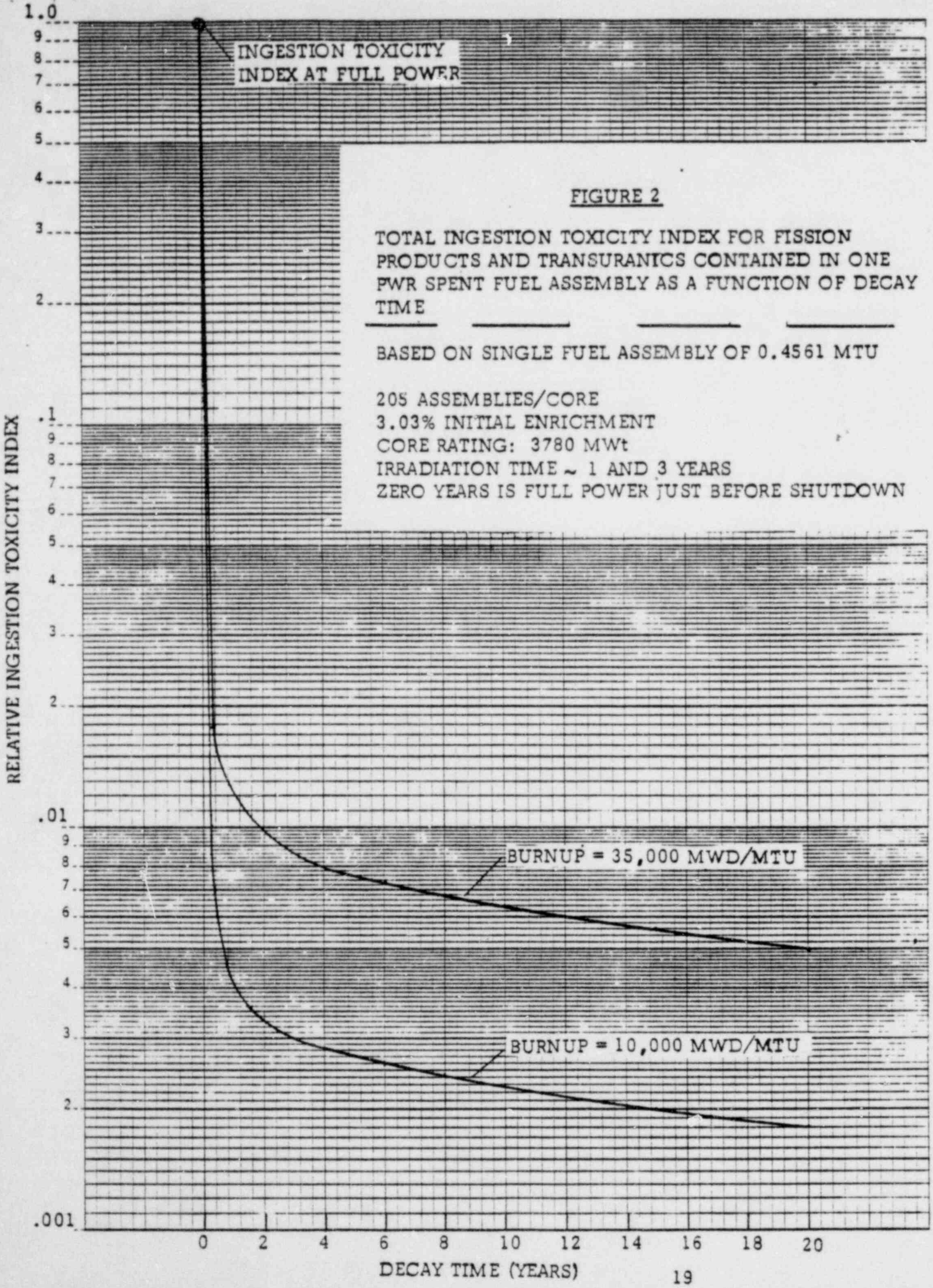


FIGURE 2

TOTAL INGESTION TOXICITY INDEX FOR FISSION PRODUCTS AND TRANSURANICS CONTAINED IN ONE PWR SPENT FUEL ASSEMBLY AS A FUNCTION OF DECAY TIME

BASED ON SINGLE FUEL ASSEMBLY OF 0.4561 MTU

205 ASSEMBLIES/CORE
3.03% INITIAL ENRICHMENT
CORE RATING: 3780 MWt
IRRADIATION TIME ~ 1 AND 3 YEARS
ZERO YEARS IS FULL POWER JUST BEFORE SHUTDOWN

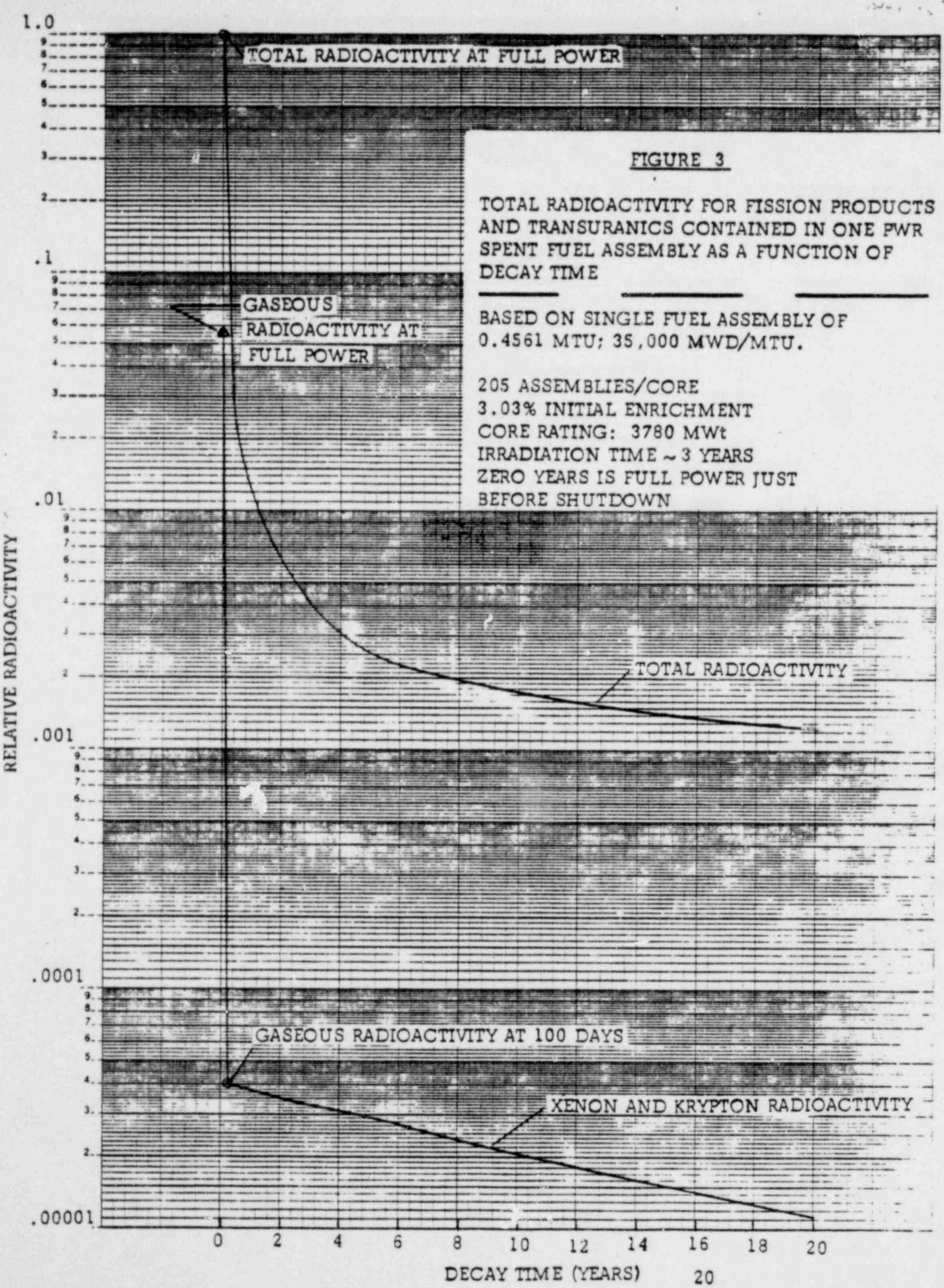


FIGURE 3

TOTAL RADIOACTIVITY FOR FISSION PRODUCTS AND TRANSURANICS CONTAINED IN ONE PWR SPENT FUEL ASSEMBLY AS A FUNCTION OF DECAY TIME

BASED ON SINGLE FUEL ASSEMBLY OF 0.4561 MTU; 35,000 MWD/MTU.

205 ASSEMBLIES/CORE
3.03% INITIAL ENRICHMENT
CORE RATING: 3780 MWt
IRRADIATION TIME ~ 3 YEARS
ZERO YEARS IS FULL POWER JUST BEFORE SHUTDOWN

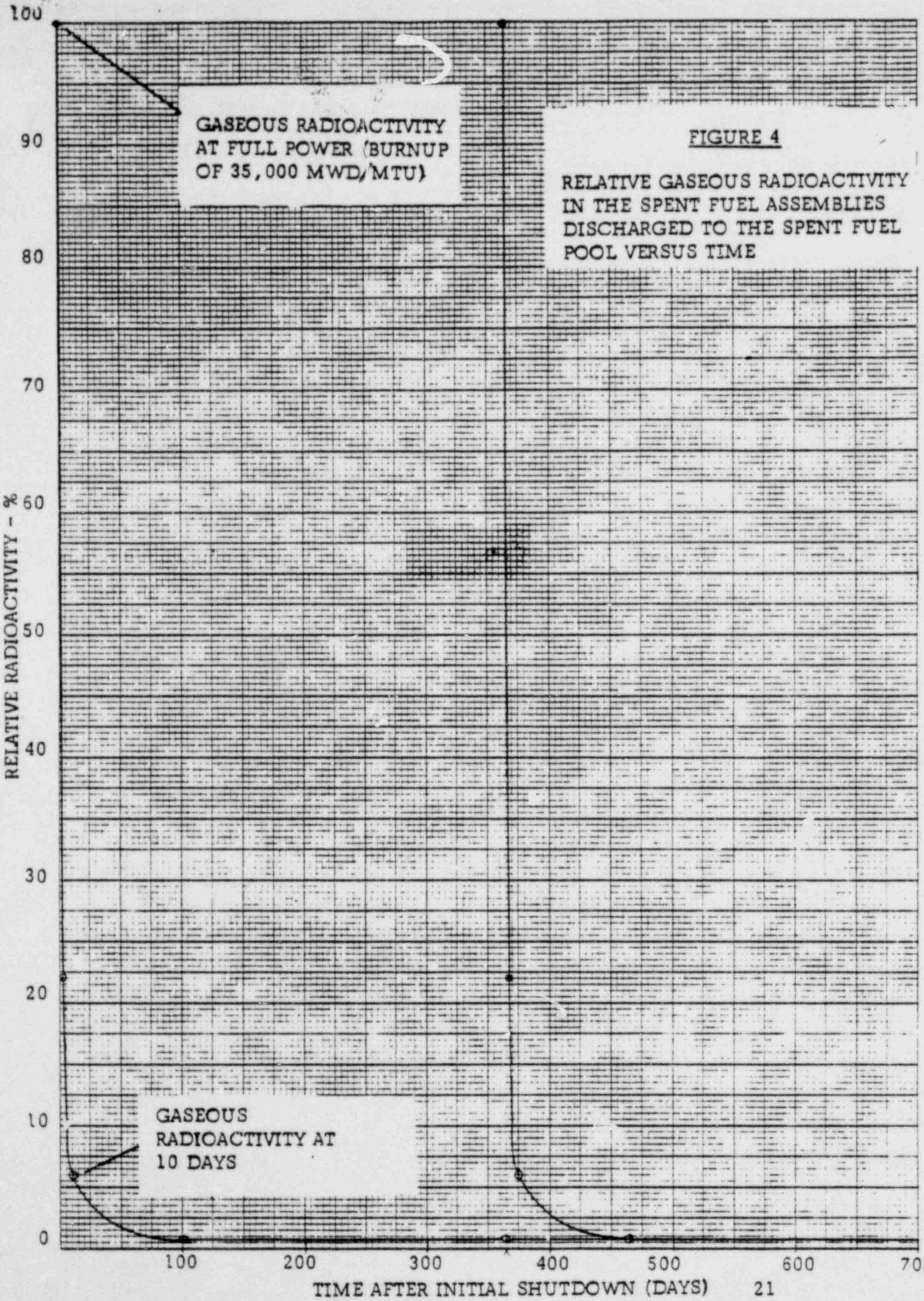


FIGURE 4

RELATIVE GASEOUS RADIOACTIVITY IN THE SPENT FUEL ASSEMBLIES DISCHARGED TO THE SPENT FUEL POOL VERSUS TIME