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Radiation levels and absorbed doses around copper canisters containing spent LWR fuel

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ASEA-ATOM, Västerås, Sweden, 1982-08-11

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RADIATION LEVELS AND ABSORBED DOSES AROUND COPPER CANISTERS CONTAINING SPENT LWR FUEL

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A list of other reports published in this series during 1982, 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.

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Radiation levels and absorbed doses around copper canisters containing spent LWR fuel

Sammanfattning Abstract

Spent fuel from Swedish LWRs is planned to be enclosed in canisters of copper and be buried in the final repository. The radiation levels during handling of canisters and the radiation energy absorbed in water (causing radiolysis) have previously been reported in KBS TR-106. However, there exists a desire to enclose BWR/PWR fuel with higher burnup and use canisters with thinner walls. New radiation source term calculations have been made available and a new concept for making canisters has also been discussed. All this has given rise to a need for new radiation shielding calculations, which are presented in this report.

This work was initiated and sponsored by KBS.

Distribution K, K Hannerz, Lönnerberg, KP, KPB, KPC,
AF Waltersten

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1
Introduction

Spent fuel from Swedish LWRs is planned to be enclosed in canisters of copper and to be buried in the final repository. Two types of canister have been discussed:

- Rods from spent BWR or PWR fuel are placed in a cylindrical canister of copper. Fuel corresponding to about 1.4 (BWR) or 1.1 (PWR) tonnes of uranium are assumed to fit in one canister. The rest of the space in the canister is filled with lead before sealing.
- Seven BWR or two PWR fuel assemblies are placed in a cylindrical canister of copper. With the help of hot isostatic pressure (HIP) the rest of the space is filled with copper and the canister is sealed.

The above two types of canister are in the following description designated as KBS-2 and KBS-3, respectively.

The radiation levels during handling of canisters and the radiation energy absorbed in water (causing radiolysis) have previously been reported (reference 1). A KBS-2 canister with wall thickness 20 cm, average fuel burnup of 30 Mwd/kg U (BWR fuel) and a cooling time of 40 years before putting into canisters were assumed.

There exists a desire to enclose both BWR and PWR fuel with higher burnup and use canisters with thinner walls. New radiation source term calculations have also been made available (reference 2), giving rise to a need for new radiation calculations. Together with KBS it has been decided to perform calculations for the following set of parameters:

Type of canister	KBS-2						KBS-3	
Type of fuel	BWR	BWR	BWR	PWR	PWR	PWR	BWR	PWR
Burnup (Mwd/kgU)	33	33	33	33	38	45	33	38
Wall thickness (cm)	1	10	20	10	10	10	6	6

The fuel is assumed to be put into canisters after a cooling period of 40 years but the influence of a shorter period (30 years) has also been examined. The calculatiion of radiation energy absorbed in water outside the canister is performed for the period 40 to 10^6 years after discharge of the fuel from the reactor. Absorbed dose in the event of any water inside the canisters (in direct contact with the uranium) has also been estimated. This is done assuming a decay period of 40 or 10^5 years.

2
Radiation source terms

The formation of fission products and actinides in LWR fuel during operation and the resulting gamma and neutron source terms have been calculated with the ORIGEN-2 computer code. These calculations are described in reference 2. The photon spectra have been divided into 10 energy groups with fixed mean energies. The neutrons originate from heavy isotopes with relatively short spontaneous fission half-lives or (α, n) reactions in 0-18 and 0-17 present in UO_2-fuel. These two types of neutrons emitted are treated separately because of different spectra.

The upper part of a fuel rod contains springs of stainless steel.An assembly also contains a top tie plate of the same material. These components are neutron irradiated during reactor operation causing induced activity. After some years of operation the dominant gamma emitter is Co-60. This gamma source is small compared with the fuel itself but is important for the radiation levels in the upward axial direction of the canisters and has therefore been calculated using the computer code AKTGAMMA (reference 3). The cobalt content in the stainless steel is assumed to be 0.05 or 0.2 % for BWR or PWR fuel, respectively (In ASEA-ATOM fuel the cobalt content is restricted to 0.05 %.)

When some of the neutrons emitted from the fuel are captured in the different materials around the fuel, hard energy photons will be emitted. The capture rate in the different materials has been calculated together with the neutron transport calculations. These capture rates have been combined with gamma spectra from references 4 and 5 to give gamma source terms.

3
Gamma and neutron transport calculations

The gamma transport calculations have been carried out with the point kernel codes CYLGAM and CYLGAX (reference 6). The one-dimensional S_n code ANISN (reference 7) has been used for the neutron transport calculations. Conversion factors from reference 8 have been used to obtain dose rates (mSv/h) from neutron fluxes (n/cm^2, s). The deposition of energy to water outside the canister due to elastic scattering of neutrons was calculated from the neutron fluxes. It was found that more than 90 % of that energy was due to collisions with hydrogen. Together with the neutron fluxes, neutron capture rates in different materials were calculated with ANISN (giving the gamma source terms from neutron capture, see section 2).

The canisters and the source regions have been homogenized, assuming cylindrical geometry. Transport calculations have been carried out both in the mid radial and the upward axial directions. The treated geometries and the homogenized regions are described in table 1 and 2.

All cases except one are assumed to give a radiation field with rotational symmetry. The exception is a KBS-3 canister with 2 PWR assemblies, having higher radiation levels in two directions. The calculated values correspond to these maximum directions and are estimated to be about a factor of two higher than the average value in the radial direction.

4
Radiation levels during handling of canisters

With the source terms described in section 2 and the calculation methods described in section 3 the radiation levels outside the canisters have been calculated both in the mid radial and upward axial directions. Dose rates at 3 different distances from the canisters (at contact, 1 m from and 2,5 m from) are presented in table 3, 4 and 5.

The handling of canisters is assumed to take place after a decay period of 40 years. A decay period of only 30 years was found to increase the gamma and the neutron dose rates in the radial direction by 42 % and 56 %, respectively. From the results could also be seen, that both a thicker copper shield and a higher burnup level increase the relative importance of the neutrons. No big difference is seen between canisters containing BWR or PWR fuel. Neutron induced activity (i.e. Co-60) in stainless steel was found to give the major contribution to the gamma dose rates in the upward direction.

The axial distribution of the gamma source in the fuel is closely related to the burnup profile. This is considered by using typical burnup profiles for BWR and PWR fuel. Cm-244 is the dominant neutron emitter at a decay time of 40 years. The relation between burnup and Cm-244 concentration is shown in reference 1, which has been used to estimate the axial neutron source profile.

5. Radiation energy absorbed in water outside the canisters

The canisters are assumed to be surrended by a layer of clay mineral called Bentonite in the final repository. This mineral is assumed to have a dry density of 1,75 g/cm^3 with a typical chemical analysis shown in table 6 (from reference 9). The amount of mechanically held water is assumed to be 20 % or 0.35 g/cm^3. The radiation that penetrates the surface of the copper canisters causes radiolysis of the water. In order to permit quantitative evaluations of whether the radiolysis products can destroy the integrity of the canisters, a calculation has been made of the radiation energy absorbed (absorbed dose) in the water. This is done for the period 40 to 10^6 years after discharge of the fuel from the reactor. The absorbed dose is expressed in the SI unit gray (Gy) (1 Gy = 100 rad = = 1 Ws/kg = 6.24 · 10^{15} eV/g).

Dose rates (mGy/h) as a function of time after discharge are presented in figures 1-8. This is done both for positions on the surface and 10 cm from the surface of the canisters and the contributions from gamma and neutrons are shown individually. The increase of gamma dose rates between 10^4 and 2 · 10^5 years is due to the buildup of Ra-226 in the fuel.

The calculated dose rates have been numerically integrated, giving accumulated doses (Gy) to water outside the canisters. These are presented as a function of time in figures 9-16 and as a function of distance from the surface of the canisters in figures 17-24. It is obvious from the figures that the buildup of Ra-226 causes a significant increase of accumulated dose between 3 · 10^4 and 10^6 years. The dose due to neutrons decreases somewhat faster with the distance from the surface than the gamma dose.

The total energy depositions (MWs) to water outside the canisters have been obtained by integrating the accumulated doses over the amount of water outside the canisters. The results are presented as a function of time in figures 25-32 and as a function of distance from the surface of the canisters in figures 33-40. 45-75 % of the gamma and 80-85 % of the neutron energy deposition to water take place in the first 10 cm of the Bentonite layer outside the canisters.

6

Radiation energy absorbed in water inside the canisters

A rough estimate of the radiation energy deposition to water in the event of direct contact with the UO_2 fuel has been made. The basis for calculations has been a KBS-2 canister loaded with BWR (33 MWd/kgU) or PWR (38 and 45 MWd/kg U) fuel and decay periods of 40 or 10^5 years.

The results are divided into contribution from α -, β - and γ -radiation (the contribution from neutrons can be neglected) and are presented in table 7. The figures are valid for the case of water in a narrow crack in the UO_2-pellet. The crack width should not exceed the ranges of the α - and β -particles in water, which for the energies considered are:

α -particles:	0.02	-	0.075	mm
β -particles:	1	-	20	mm

If, instead, the water is in a thin layer on the outer surface of a pellet, the contribution from α and β will be halved while the contribution from γ is unaffected. Water outside the cladding of a fuel rod will be affected mainly by the γ -radiation.

7
Discussion

The calculation results in this report have been compared with the results in the previous report (reference 1). This comparison is summarized in table 8.

A very good agreement is obtained for the neutron radiation levels outside a 20 cm KBS-2 canister loaded with BWR fuel, especially if a correction is made for the difference in burnup. The difference in gamma radiation level is due to different gamma source term representations in the computer codes used (ORIGEN-2 in this report and BEGAFIP in reference 1). At a decay time of 40 years Cs-137 is the dominant gamma emitter. The fixed mean group energy used in ORIGEN-2 (0.575 MeV instead of the true 0.662 for Cs-137) explains the difference and the gamma radiation levels given in reference 1 are therefore probably more accurate. The difference will be less in the case of a thinner copper shield.

Reasonably good agreement is reached for calculated energy depositions to water outside a 20 cm KBS-2 canister loaded with BWR fuel apart from the contribution from neutrons during the time period 10^4 - 10^6 years. The very complete neutron source term library in ORIGEN - 2 was not available at the time for the previous calculations. Therefore the results presented in this report should be regarded as more accurate.

The above comparison indicates an uncertainty in presented values of the order of a factor of two.

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TABLE 1

Calculation models for KBS-2 canisters

Radial direction

R (cm)	Composition (g/cm^3)
0 - 2.8	Pb 11.34
2.8 - 3.3	Cu 8.93
3.3 - 18.5	BWR: Pb 4.70 PWR: Pb 6.23 UO_2 4.19 UO_2 3.28 Zr 0.90 Zr 0.69 Cu 0.20 Cu 0.20
18.5 - x	Cu 8.93

Upward axial direction

Z (cm)	Composition (g/cm^3)
0-365	BWR: Pb 4.70 PWR: Pb 6.23 UO_2 4.19 UO_2 3.28 Zr 0.90 Zr 0.69 Cu 0.20 Cu 0.20
365-390	BWR: Pb 4.70 PWR: Pb 6.23 Zr 0.90 Zr 0.69 SS 0.61 SS 0.46 Cu 0.20 Cu 0.20
390-394	Pb 11.34
394-x	Cu 8.93

TABLE 2 Calculation models for KBS-3 canisters

Radial direction (7 BWR assemblies)

R (cm)	Composition (g/cm^3)
0-24.5	Cu 6.47 UO_2 2.05 Zr 0.46
24.5-30.5	Cu 8.93

Radial direction (1 of 2 PWR assemblies)

R (cm)	Composition (g/cm^3)
0 - 13.6	Cu 6.05 UO_2 2.47 Zr 0.49
13.6 - 19.6	Cu 8.93

Upward axial direction (7 BWR assemblies)

Z (cm)	Composition (g/cm^3)
0 - 365	Cu 6.47 UO_2 2.05 Zr 0.46
365 - 390	Cu 6.47 Zr 0.46 SS 0.30
390 - 409	Cu 8.19 SS 0.31
409 - 415	Cu 8.93

(cont.)

(TABLE 2 cont.) Upward axial direction (2 PWR assemblies)

Z (cm)	Composition (g/cm^3)
0 - 365	Cu 6.05 UO_2 2.47 Zr 0.49
365 - 385	Cu 6.05 Zr 2.47 SS 0.55
385 - 405	Cu 7.62 SS 0.88
405 - 411	Cu 8.93

TABLE 3 Radiation levels (mSv/h) in the mid radial direction outside a KBS-2 canister

Fuel type		BWR	BWR	BWR	BWR	PWR	PWR	PWR
Burnup (MWd/kgU)		33	33	33	33	33	38	45
Decay period (years)		40	40	40	30	40	40	40
Copper wall (cm)		20	10	1	10	10	10	10
At contact	gamma	0.11	38	2.0E4 1)	54	29	34	40
	neutrons	0.93	4.3	8.1	6.7	2.4	4.5	10
	total	1.0	42	2.0E4	61	31	39	50
1 m from surface	gamma	0.029	8.1	2500	12	6.2	7.2	8.6
	neutrons	0.26	0.92	1.0	1.4	0.51	0.96	2.1
	total	0.29	9.0	2500	13	6.7	8.2	11
2.5 m from surface	gamma	0.014	3.5	810	4.9	2.7	3.1	3.7
	neutrons	0.12	0.40	0.33	0.62	0.22	0.41	0.92
	total	0.13	3.9	810	5.5	2.9	3.5	4.6

1) 2.0 E4 stands for $2.0 \cdot 10^4$

TABLE 4 Radiation levels (mSv/h) in the upward axial direction outside a KBS-2 canister

Fuel type		BWR	BWR	BWR	BWR	PWR	PWR	PWR
Burnup (MWd/kgU)		33	33	33	33	33	38	45
Decay period (years)		40	40	40	30	40	40	40
Copper wall (cm)		16	10	2	16	16	16	16
At contact	gamma	0.010	0.14	5.1	0.034	0.013	0.015	0.019
	neutrons	0.039	0.082	0.19	0.060	0.029	0.054	0.12
	total	0.049	0.22	5.3	0.094	0.042	0.069	0.14
1 m from surface	gamma	0.0012	0.016	0.44	0.0044	0.0017	0.0019	0.0023
	neutrons	0.0072	0.014	0.026	0.011	0.0055	0.010	0.023
	total	0.0084	0.030	0.47	0.015	0.0072	0.012	0.025
2.5 m from surface	gamma	0.00026	0.0032	0.081	0.00094	0.00035	0.00041	0.00059
	neutrons	0.0019	0.0034	0.0062	0.0030	0.0014	0.0027	0.0059
	total	0.0022	0.0066	0.087	0.0039	0.0018	0.0031	0.0065

TABLE 5

Radiation levels (mSv/h) in the mid radial and upward axial direction outside a KBS-3 canister

		Mid radial		Upward axial	
Fuel type		BWR	PWR[1)]	BWR	PWR
Burnup (Mwd/kgU)		33	38	33	38
Decay period (years)		40	40	40	40
Copper wall (cm)		6	6	6	6
At contact	gamma	410	510	3.0	9.0
	neutrons	2.1	2.3	0.0030	0.0043
	total	410	510	3.0	9.0
1 m from surface	gamma	91	80	0.25	0.42
	neutrons	0.47	0.36	0.00077	0.0013
	total	91	80	0.25	0.42
2.5 m from surface	gamma	37	31	0.051	0.076
	neutrons	0.13	0.14	0.00022	0.00031
	total	37	31	0.051	0.076

1) Not a radiation field with rotational symmetry. The radiation levels in the two maximum directions are given.

TABLE 6 Typical chemical analysis of clay mineral Bentonite, moisture free basis (from reference 9)

	Percent by Wt. (Varies between)	
Silica (SiO_2)	58.0	64.0
Alumina (Al_2O_3)	18.0	21.0
Ferric Oxide (Fe_2O_3)	2.5	2.8
Magnesia (MgO)	2.5	3.2
Lime (CaO)	0.1	1.0
Soda (Na_2O)	1.5	2.7
Potash (K_2O)	0.2	0.4
Ferrous Oxide (FeO)	0.2	0.4
Titanium Oxide (TiO_2)	0.1	0.2
Other minor constituents	0.5	0.8
Chemically-held water (H_2O)		5.64

TABLE 7 Absorbed dose rate (Gy/h) in water in a narrow crack in an UO_2-pellet

Canister Type of fuel Burnup (MWd/kgU)		KBS-2 BWR 33	KBS-2 PWR 38	KBS-2 PWR 45
Decay period 40 years	α	2000	2300	3300
	β	700	800	900
	γ	63	55	65
Decay period 10^5 years	α	5.4	6.2	7.5
	β	1.0	1.0	1.2
	γ	$11 \cdot 10^{-3}$	$9.6 \cdot 10^{-3}$	$12 \cdot 10^{-3}$

TABLE 8

Comparison between calculation results in this report and the previous evaluation (reference 1)

Radiation levels (mSv/h) outside a KBS-2 canister

		This report	Reference 1
Fuel type		BWR	BWR
Burnup (Mwd/kgU)		33	34/30 1)
Decay period (years)		40	40
Copper wall (cm)		20	20
At contact	gamma	0.11	0.17
	neutrons	0.93	0.40-0.95
	total	1.0	0.57-1.1
1 m from surface	gamma	0.029	0.046
	neutrons	0.26	0.11-0.26
	total	0.29	0.16-0.31

Energy deposition (MWs) to water outside a KBS-2 canister

Fuel type		BWR	BWR
Burnup (MWd/kgU)		33	34/30 1)
Copper wall (cm)		20	20
40 - 10^4 years	gamma	0.073	0.13
	neutrons	0.032	0.055
	total	0.11	0.18
40-10^6 years	gamma	4.2	4.6
	neutrons	1.5	0.12
	total	5.7	4.7

1) 34 MWd/kgU for the gamma and 30 MWd/kgU for the neutron calculations.

Fig 1 Dose rate to water outside a capsule
KBS-2 (t(Cu)=1 cm), BWR 33 MWd/kgU

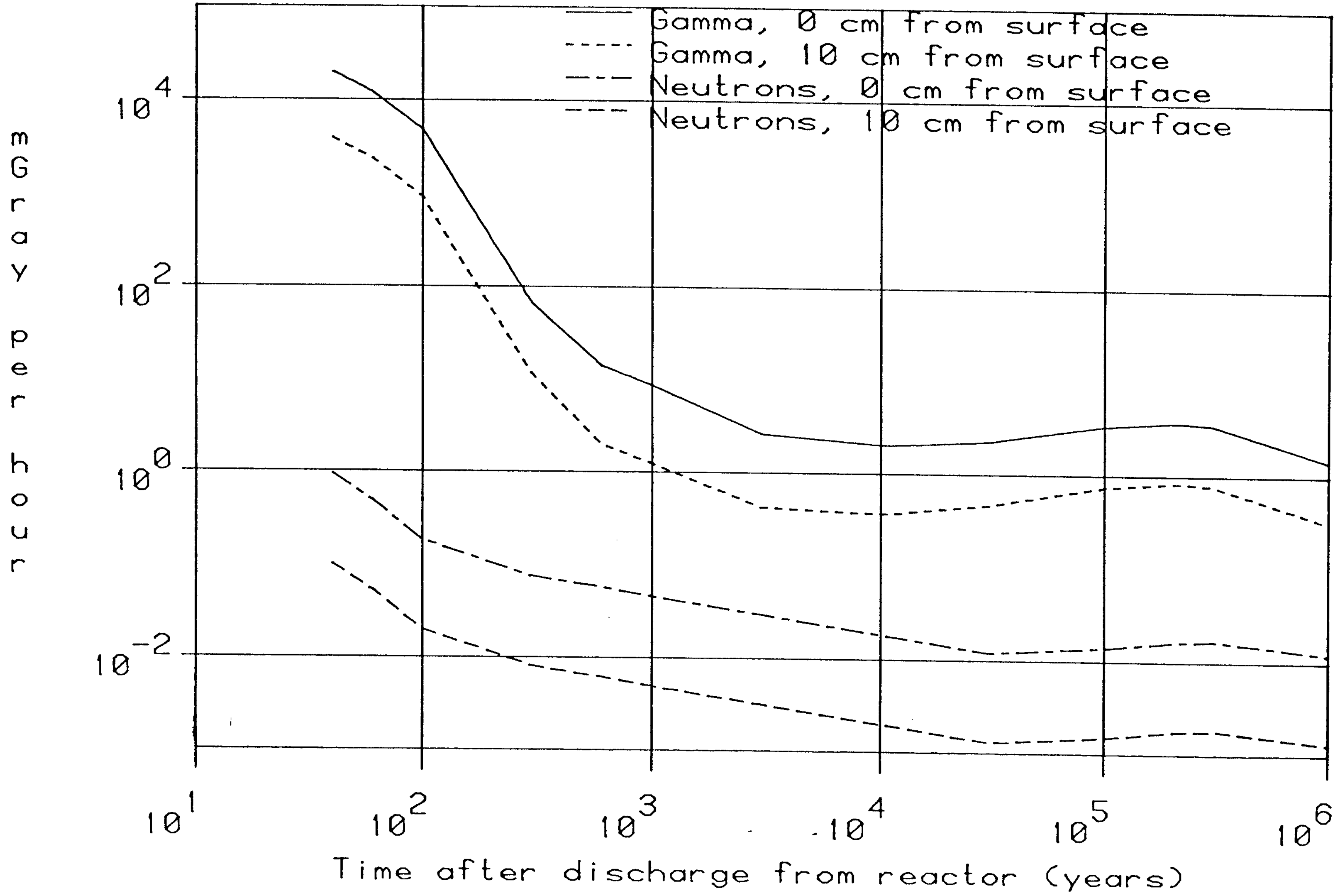

Fig 2 Dose rate to water outside a capsule
KBS-2 (t(Cu)=10 cm), BWR 33 MWd/kgU

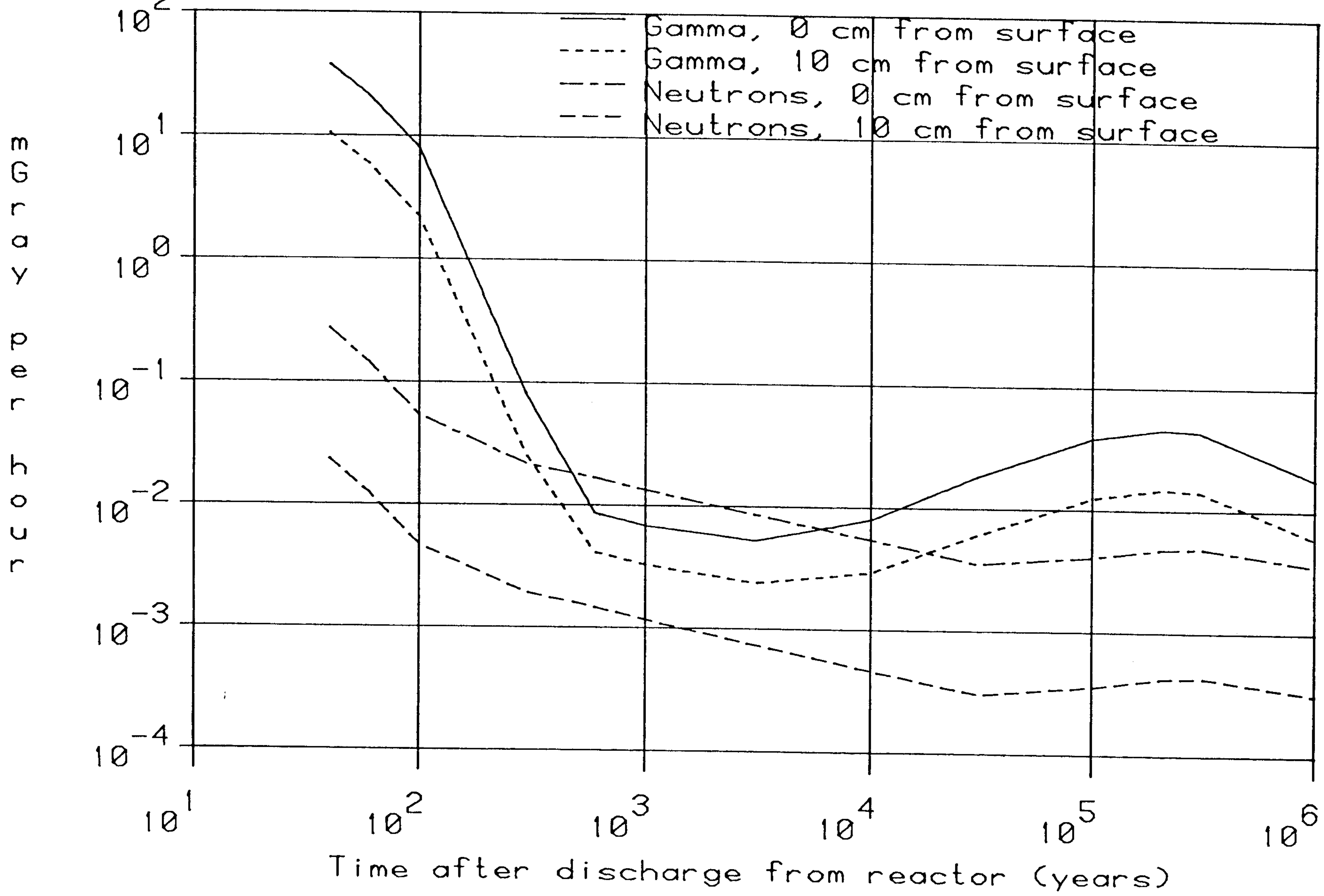

Fig 3 Dose rate to water outside a capsule
KBS-2 (t(Cu)=20 cm), BWR 33 MWd/kgU

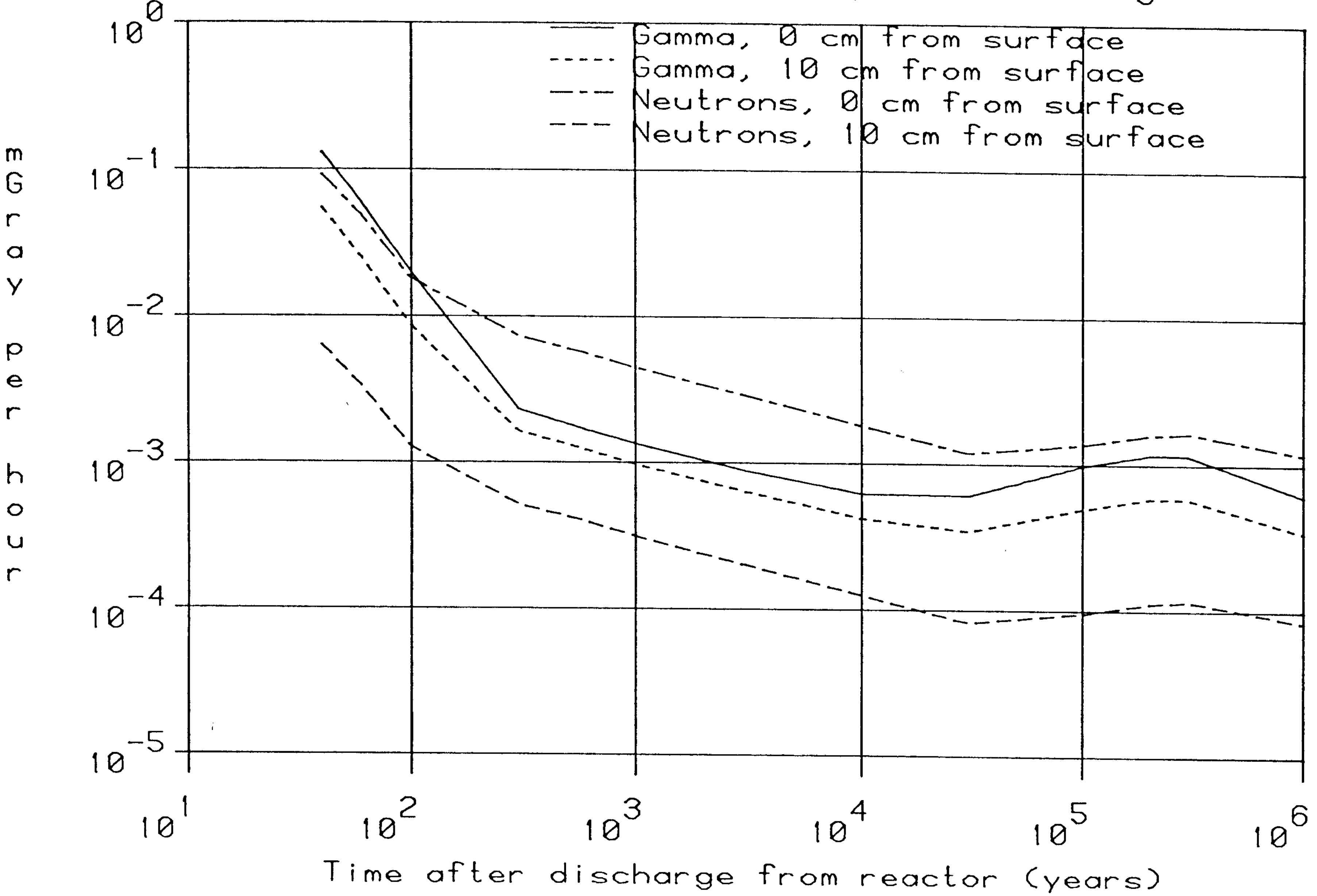

Fig 4 Dose rate to water outside a capsule
KBS-2 (t(Cu)=10 cm), PWR 33 MWd/kgU

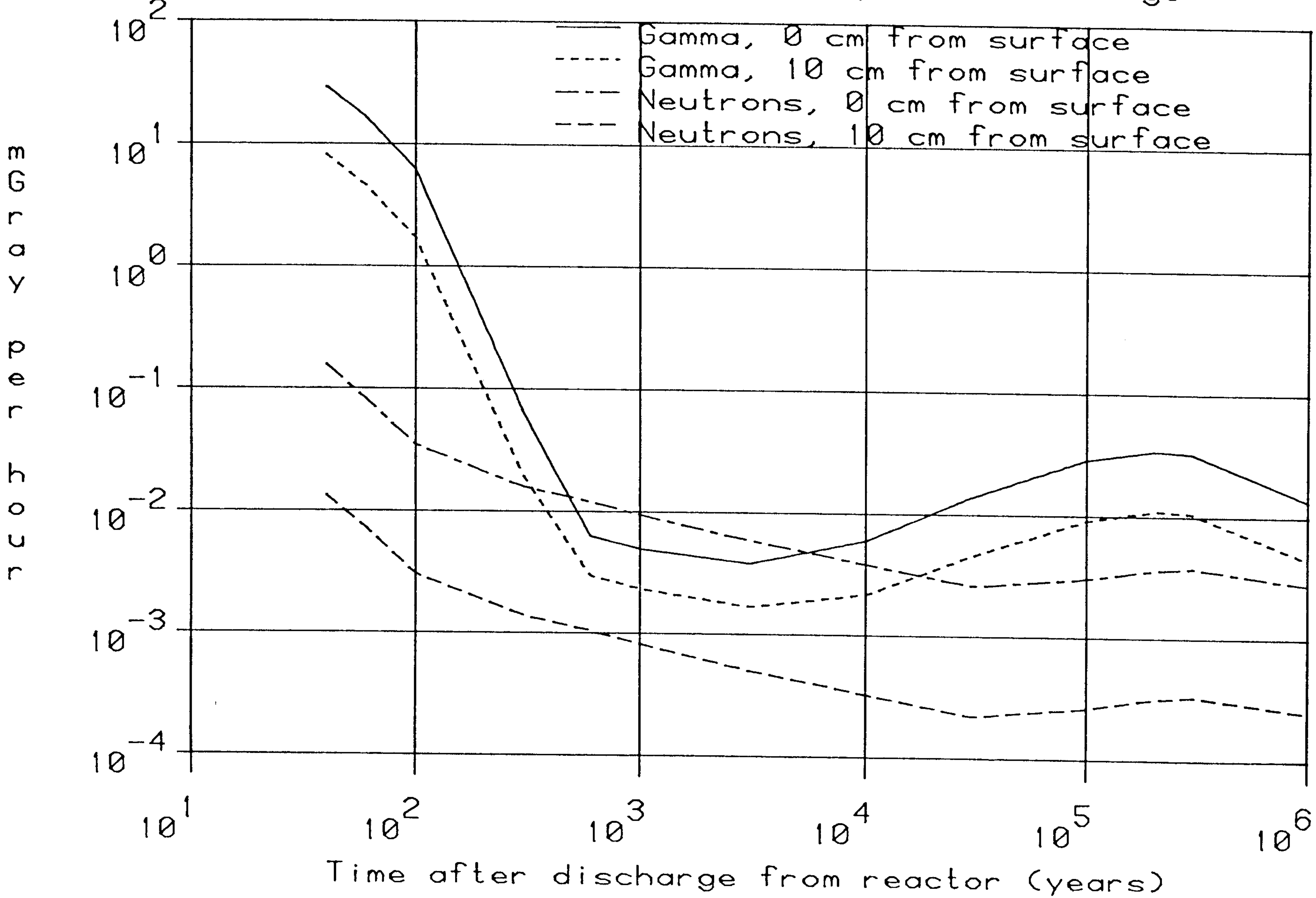

Fig 5 Dose rate to water outside a capsule
KBS-2 (t(Cu)=10 cm), PWR 38 MWd/kgU

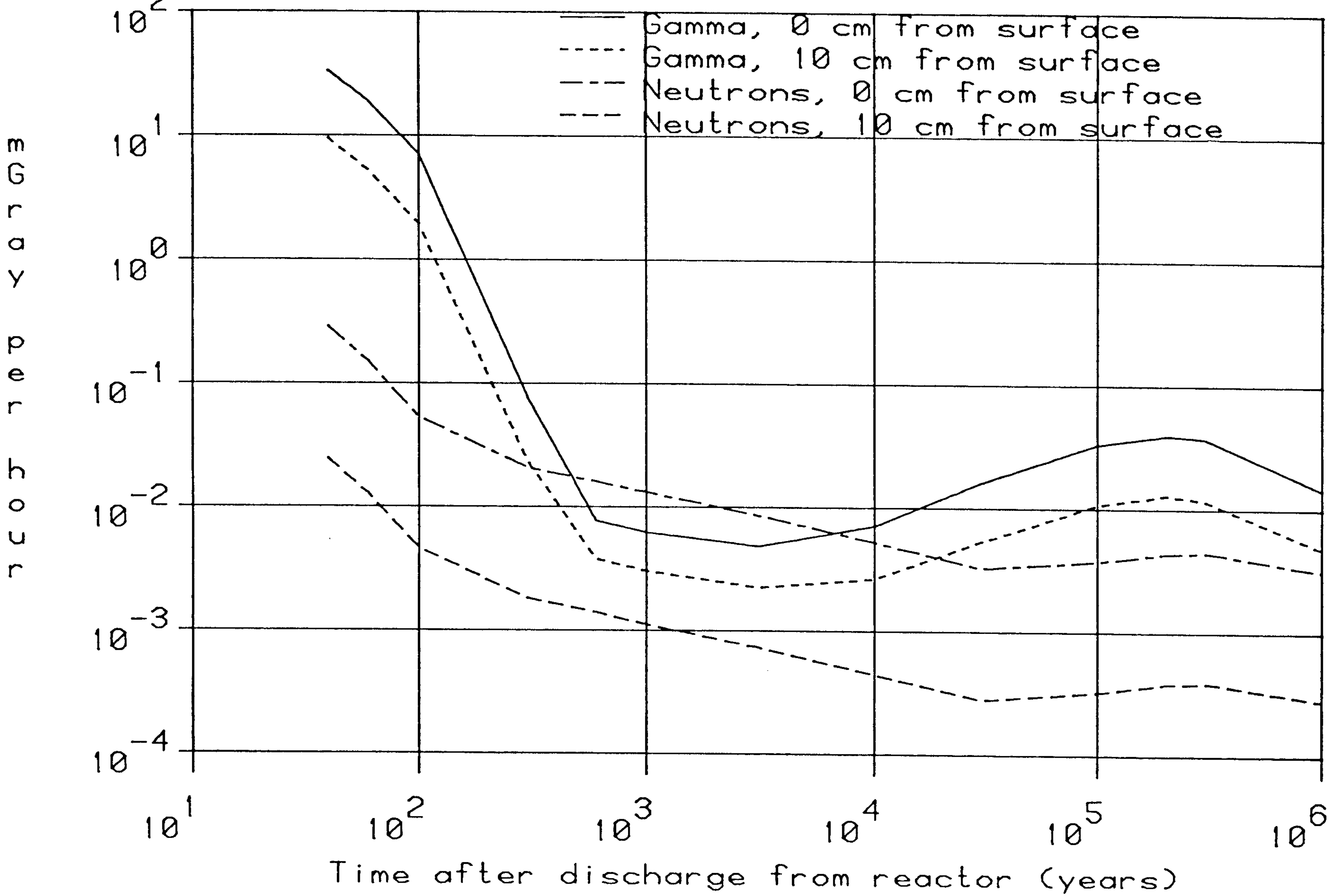

Fig 6 Dose rate to water outside a capsule KBS-2 (t(Cu)=10 cm), PWR 45 MWd/kgU

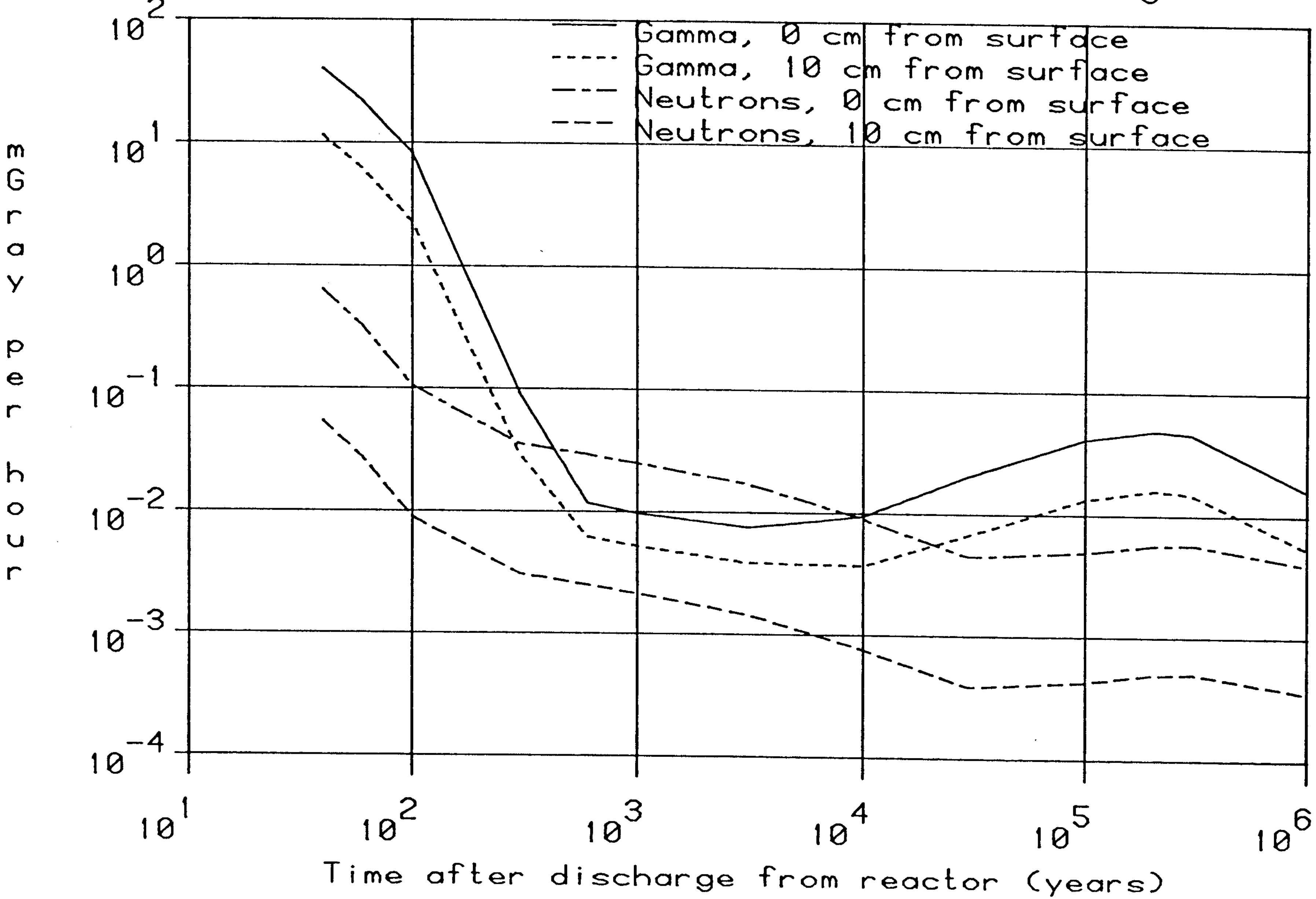

Fig 7 Dose rate to water outside a capsule KBS-3 (t(Cu)=6 cm), BWR 33 MWd/kgU

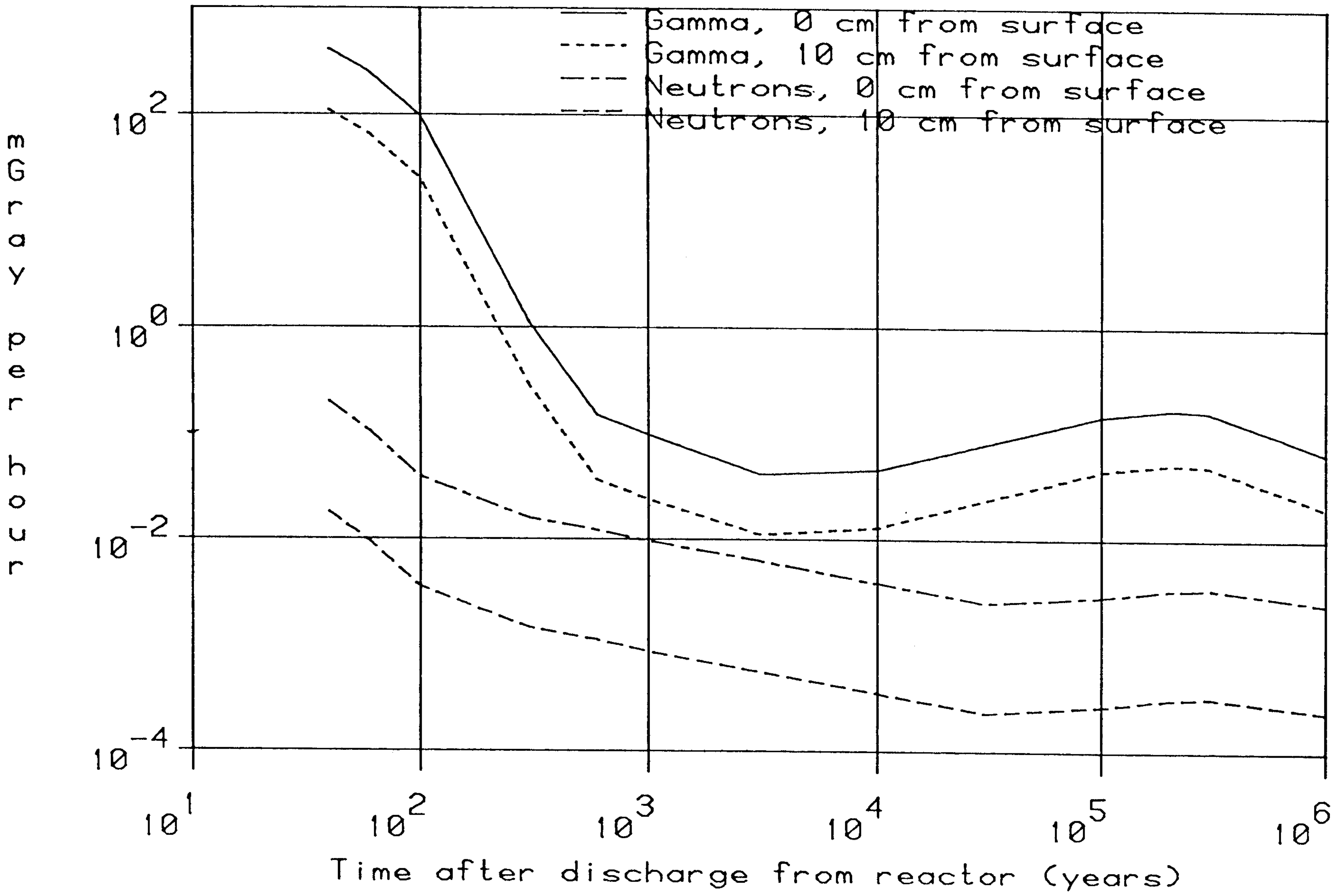

Fig 8 Dose rate to water outside a capsule
KBS-3 (t(Cu)=6 cm), PWR 38 MWd/kgU

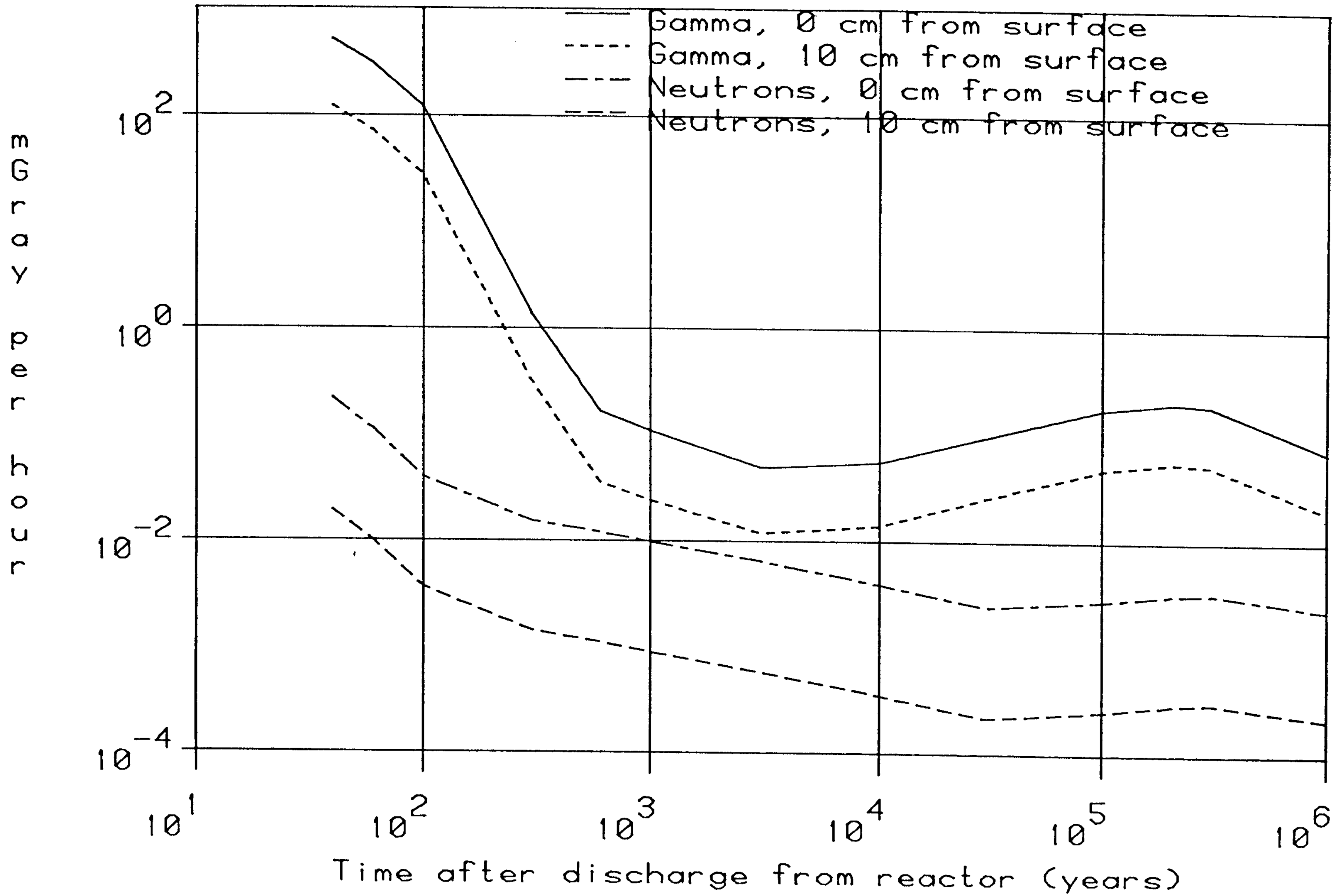

Fig 9 Accumulated dose to water outside a capsule KBS-2 (t(Cu)=1 cm), BWR 33 MWd/kgU

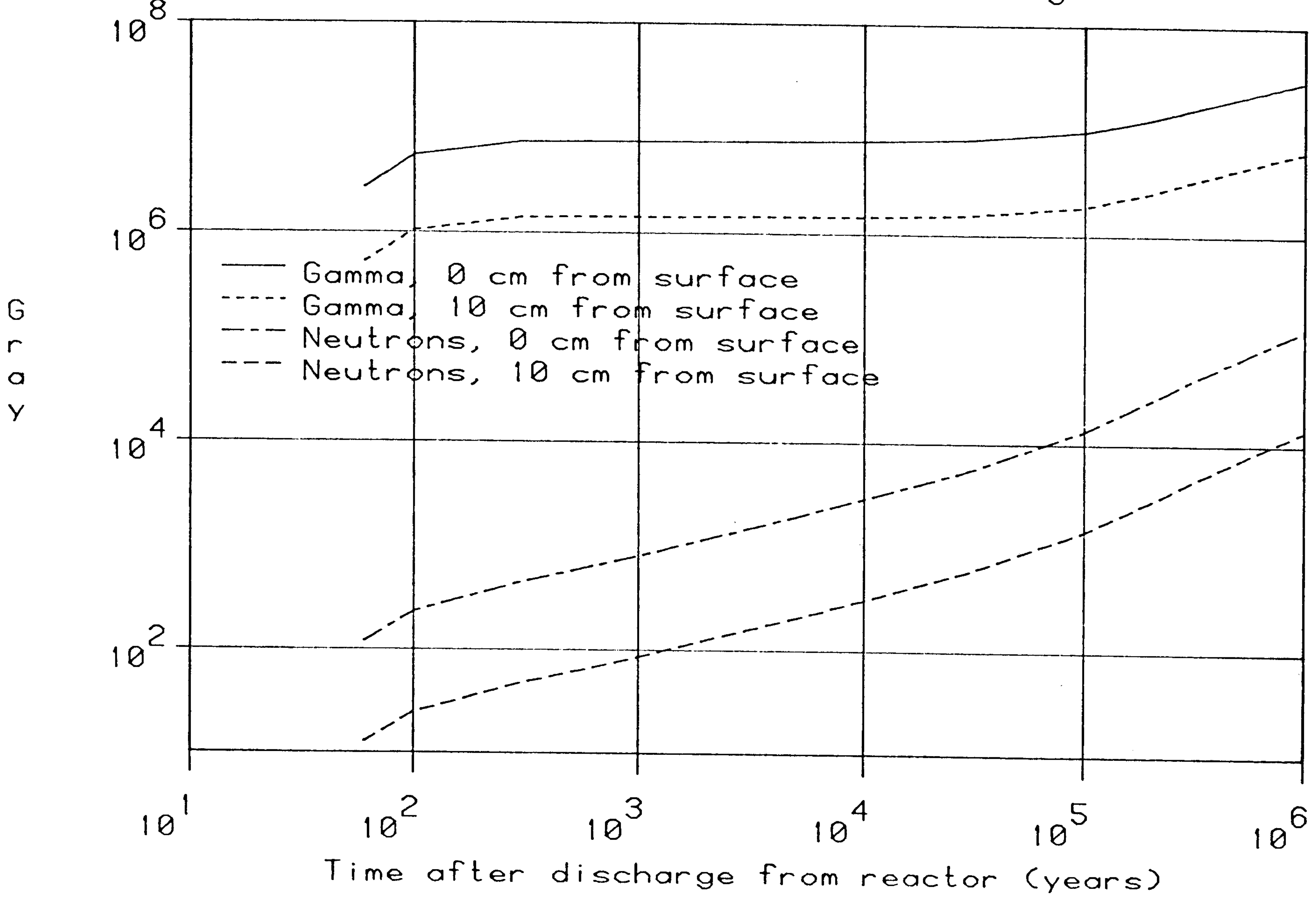

Fig 10 Accumulated dose to water outside a capsule KBS-2 (t(Cu)=10 cm), BWR 33 MWd/kgU

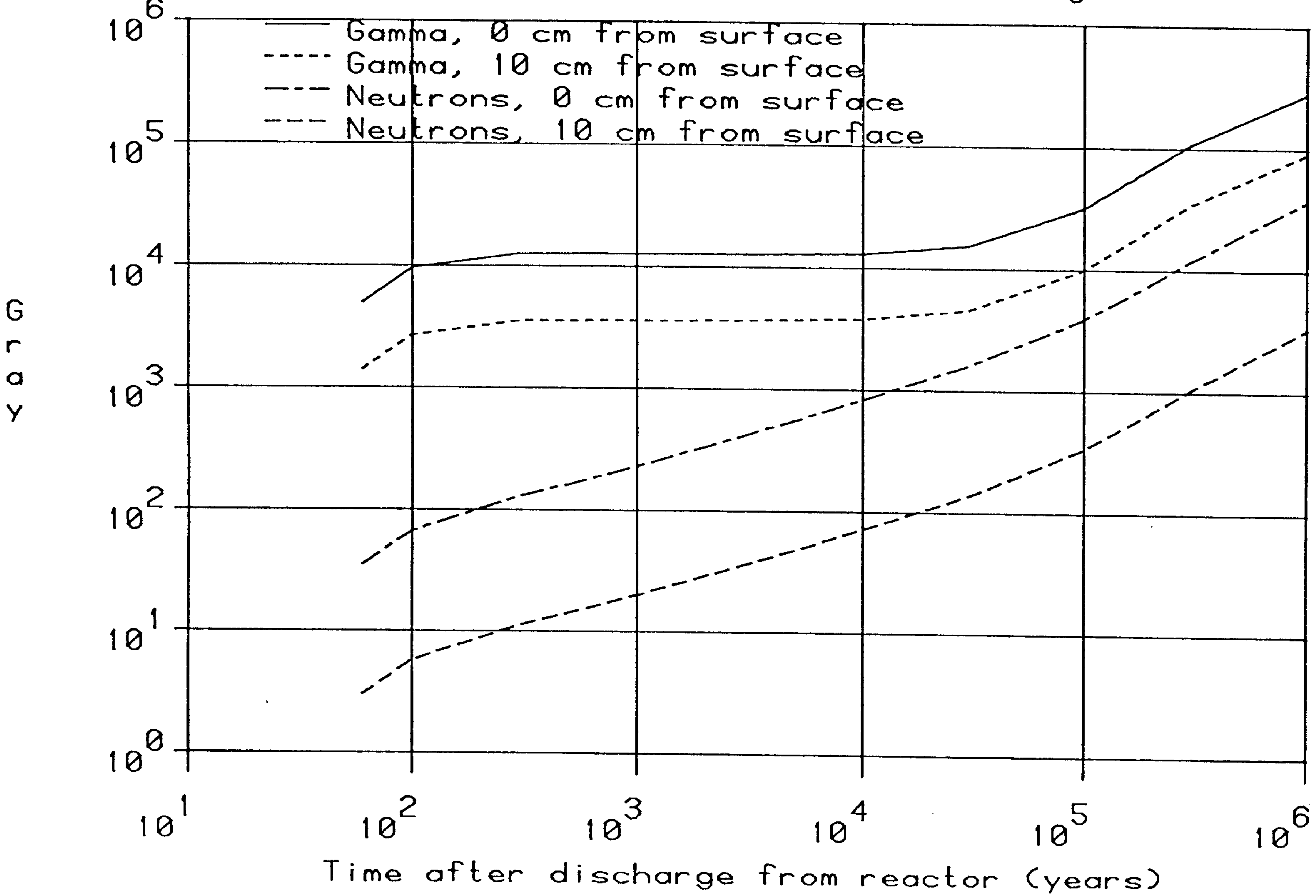

Fig 11 Accumulated dose to water outside a capsule
KBS-2 (t(Cu)=20 cm), BWR 33 MWd/kgU

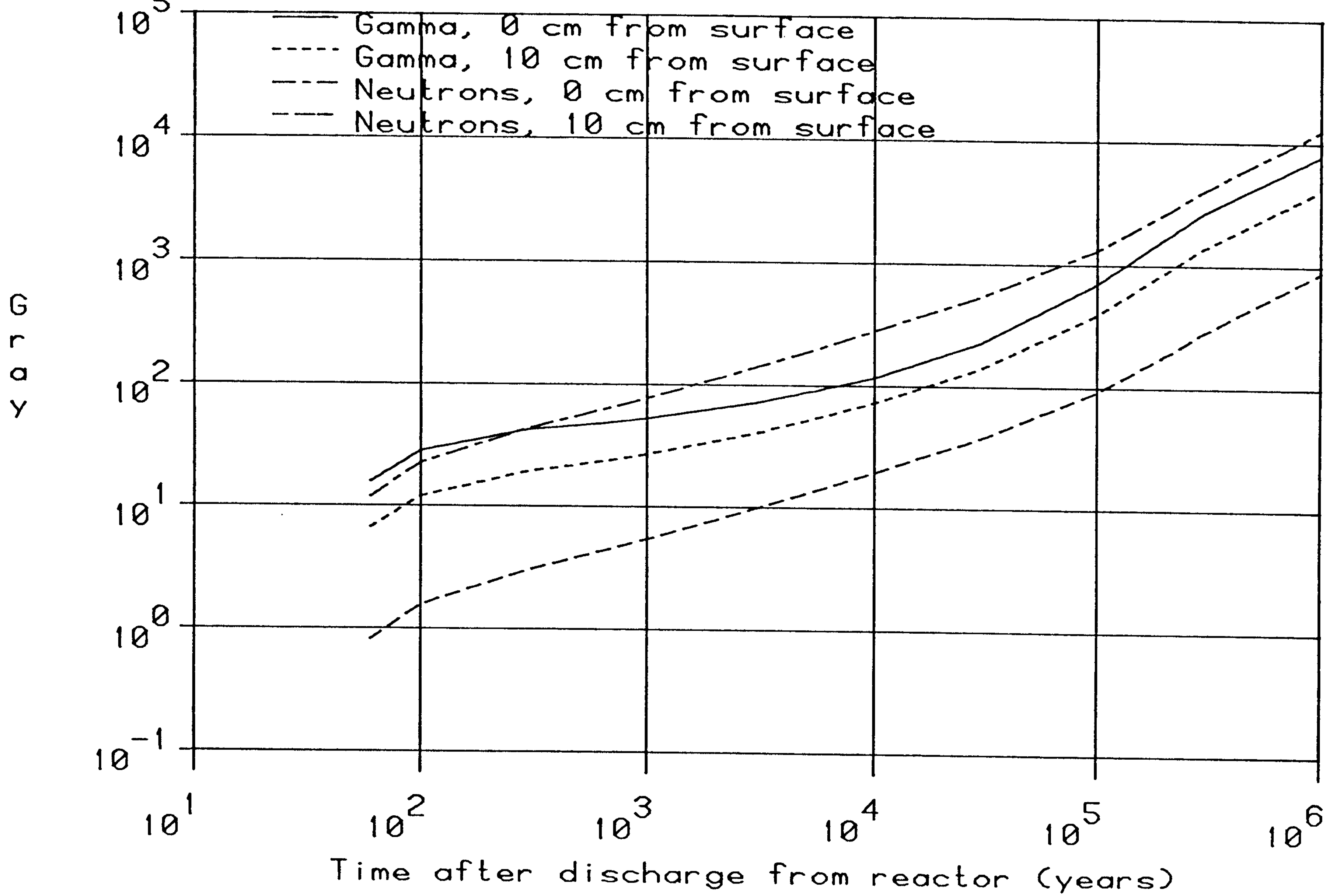

Fig 12 Accumulated dose to water outside a capsule KBS-2 (t(Cu)=10 cm), PWR 33 MWd/kgU

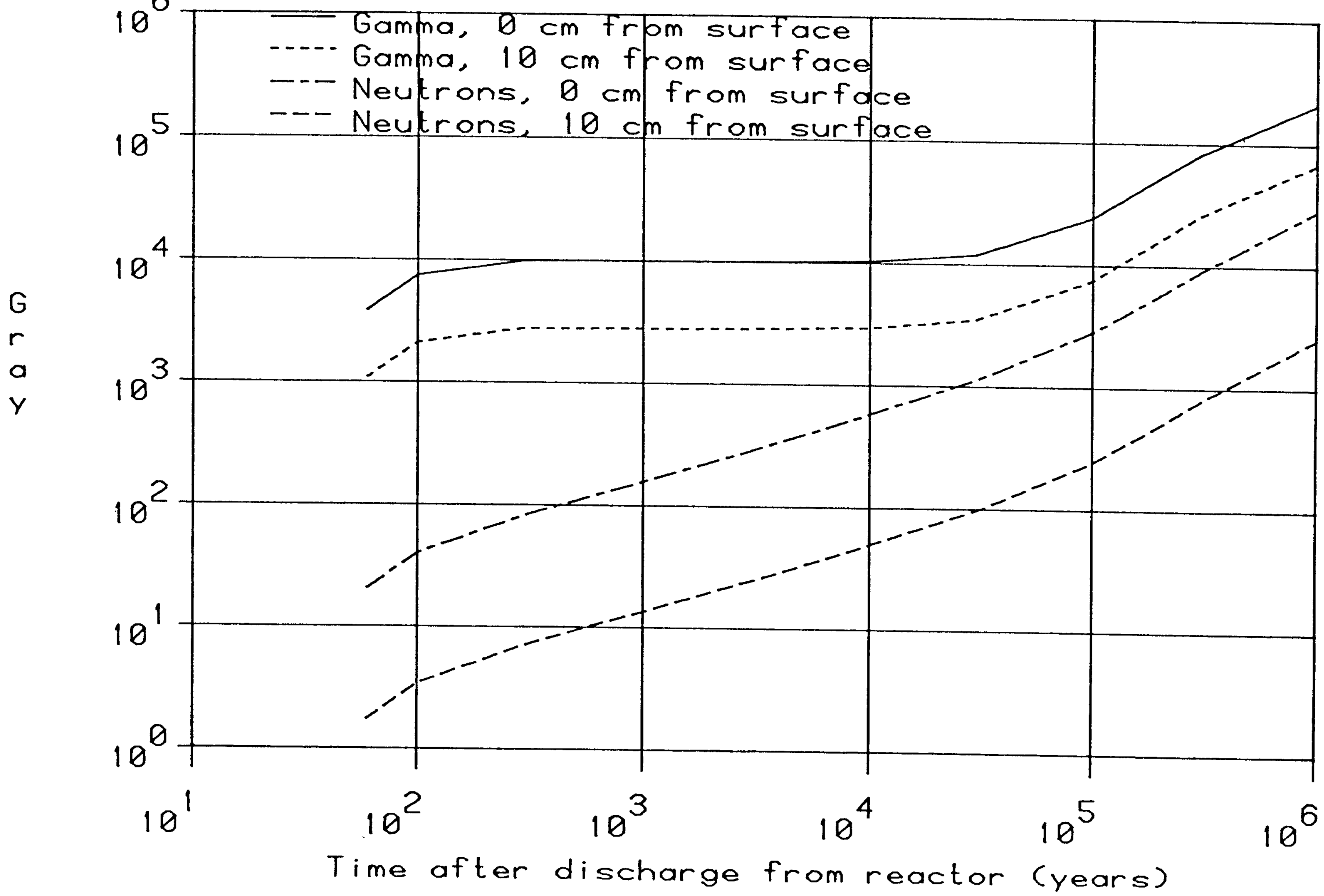

Fig 13 Accumulated dose to water outside a capsule
KBS-2 (t(Cu)=10 cm), PWR 38 MWd/kgU

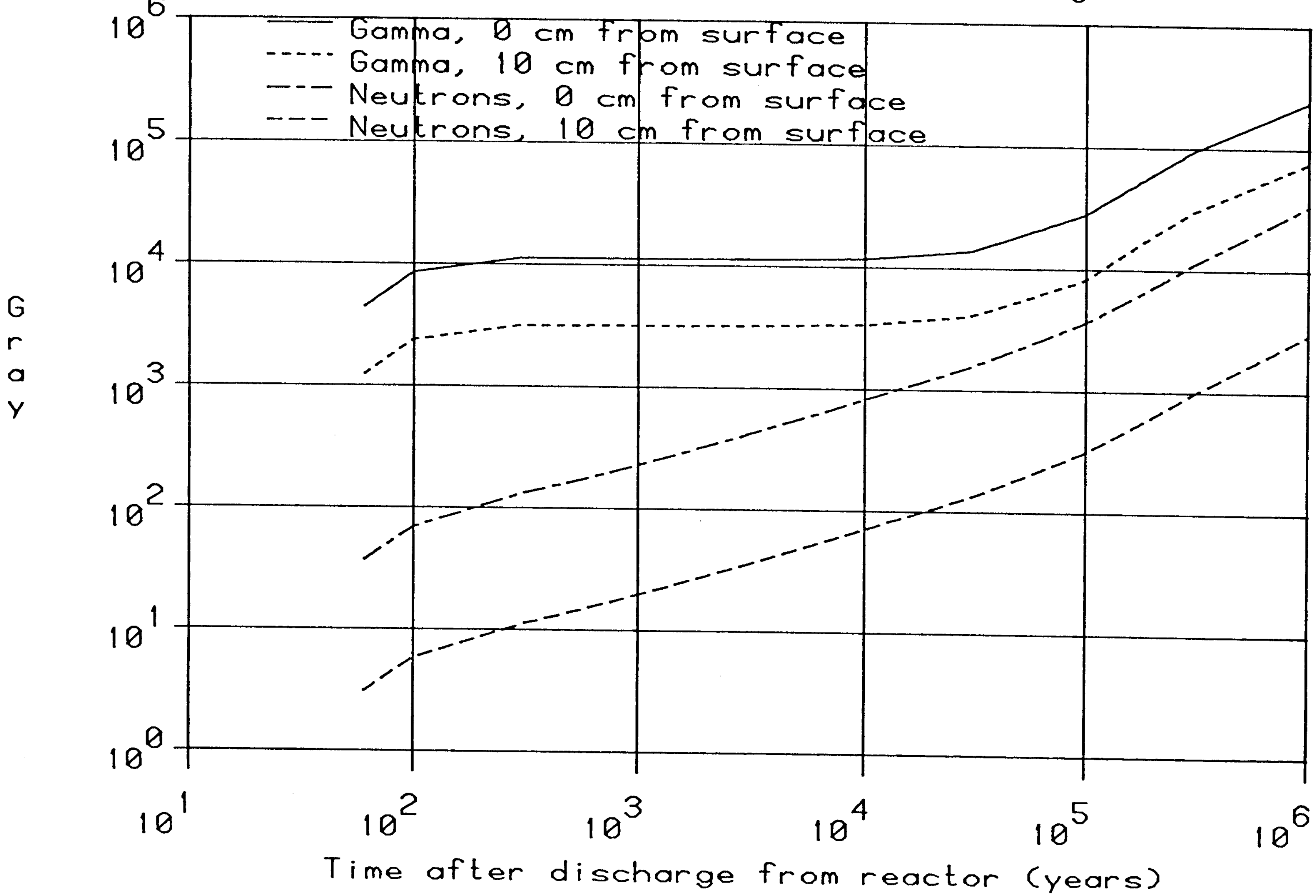

Fig 14 Accumulated dose to water outside a capsule
KBS-2 (t(Cu)=10 cm), PWR 45 MWd/kgU

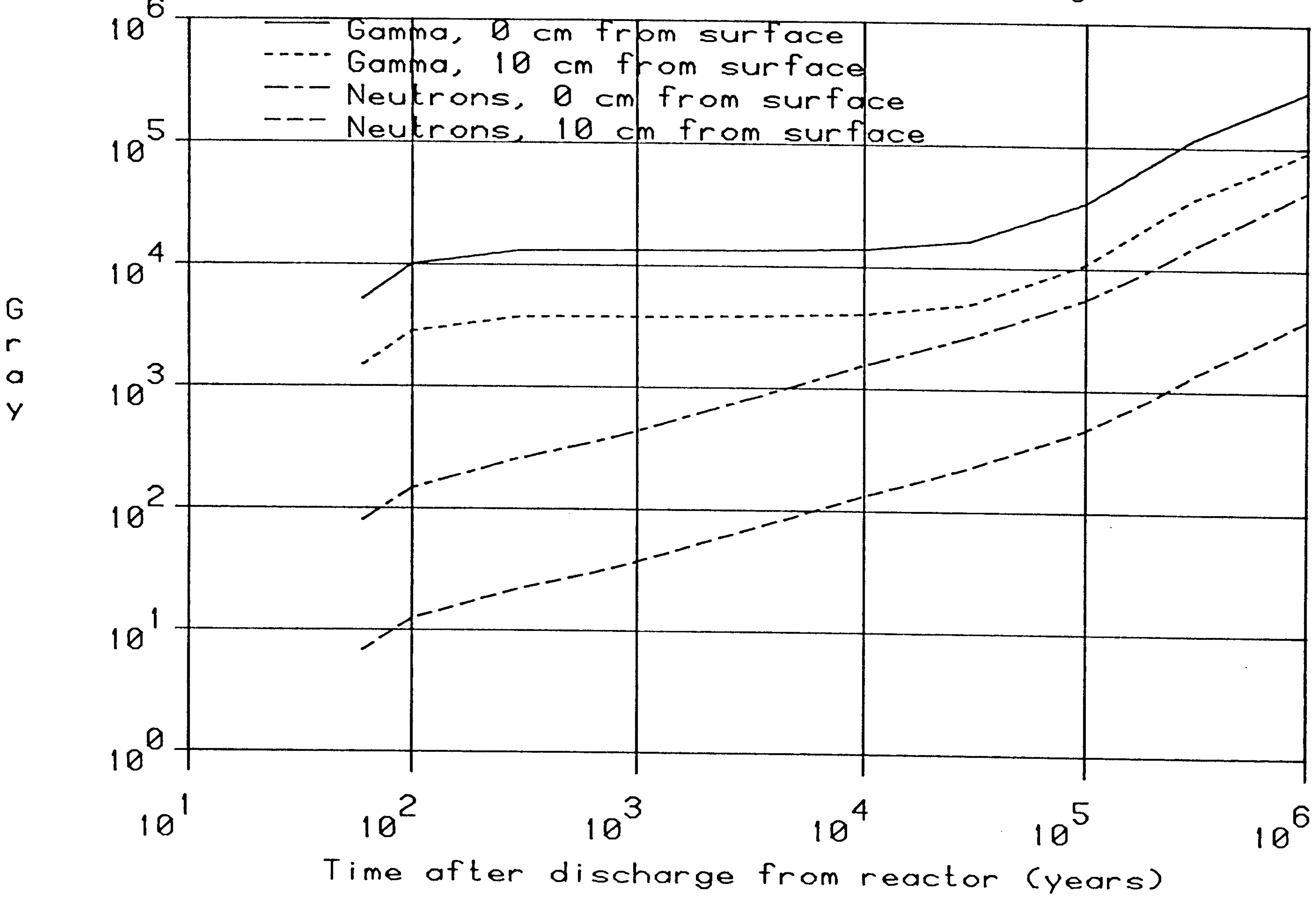

Fig 15 Accumulated dose to water outside a capsule
KBS-3 (t(Cu)=6 cm), BWR 33 MWd/kgU

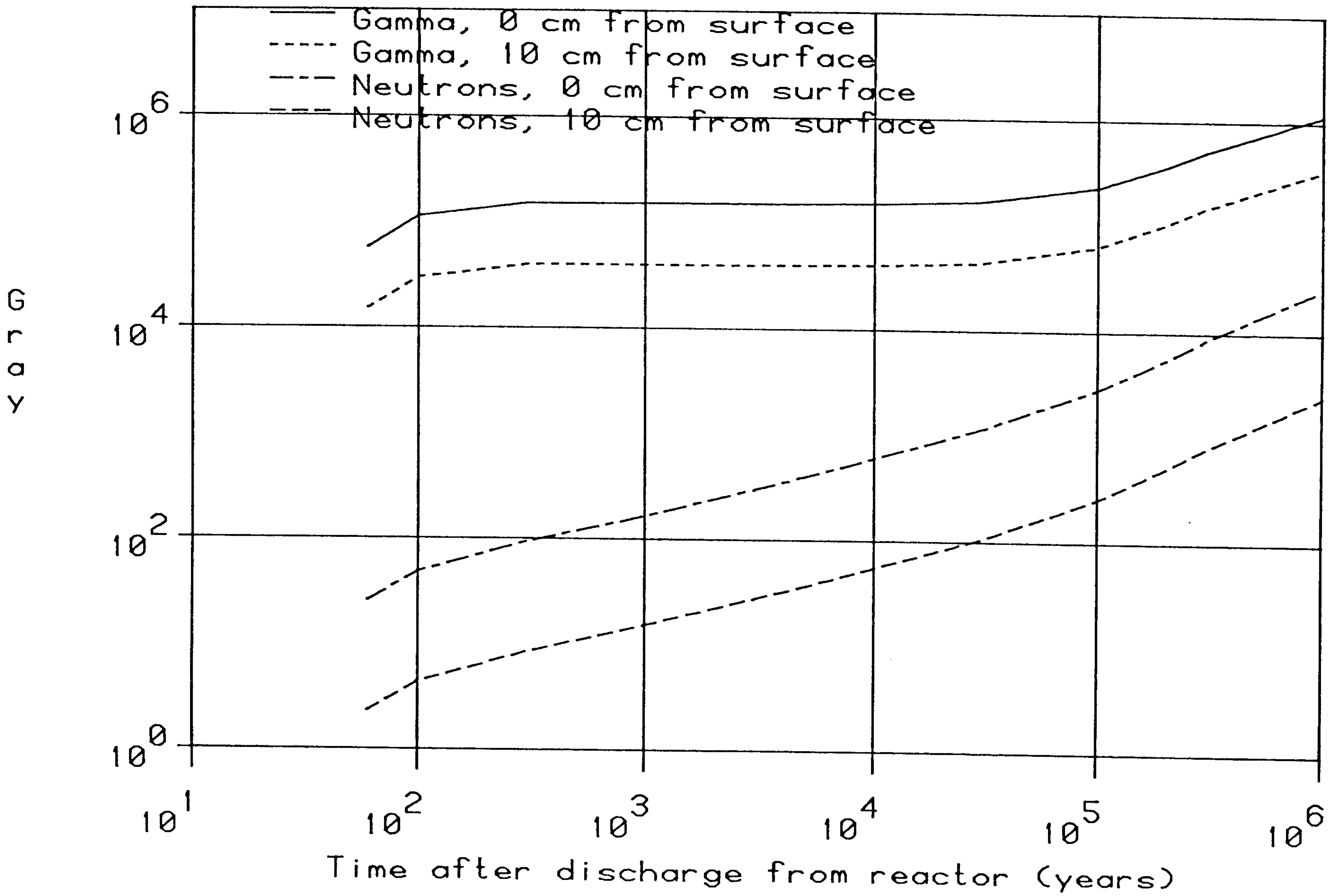

Fig 16 Accumulated dose to water outside a capsule KBS-3 (t(Cu)=6 cm), PWR 38 MWd/kgU

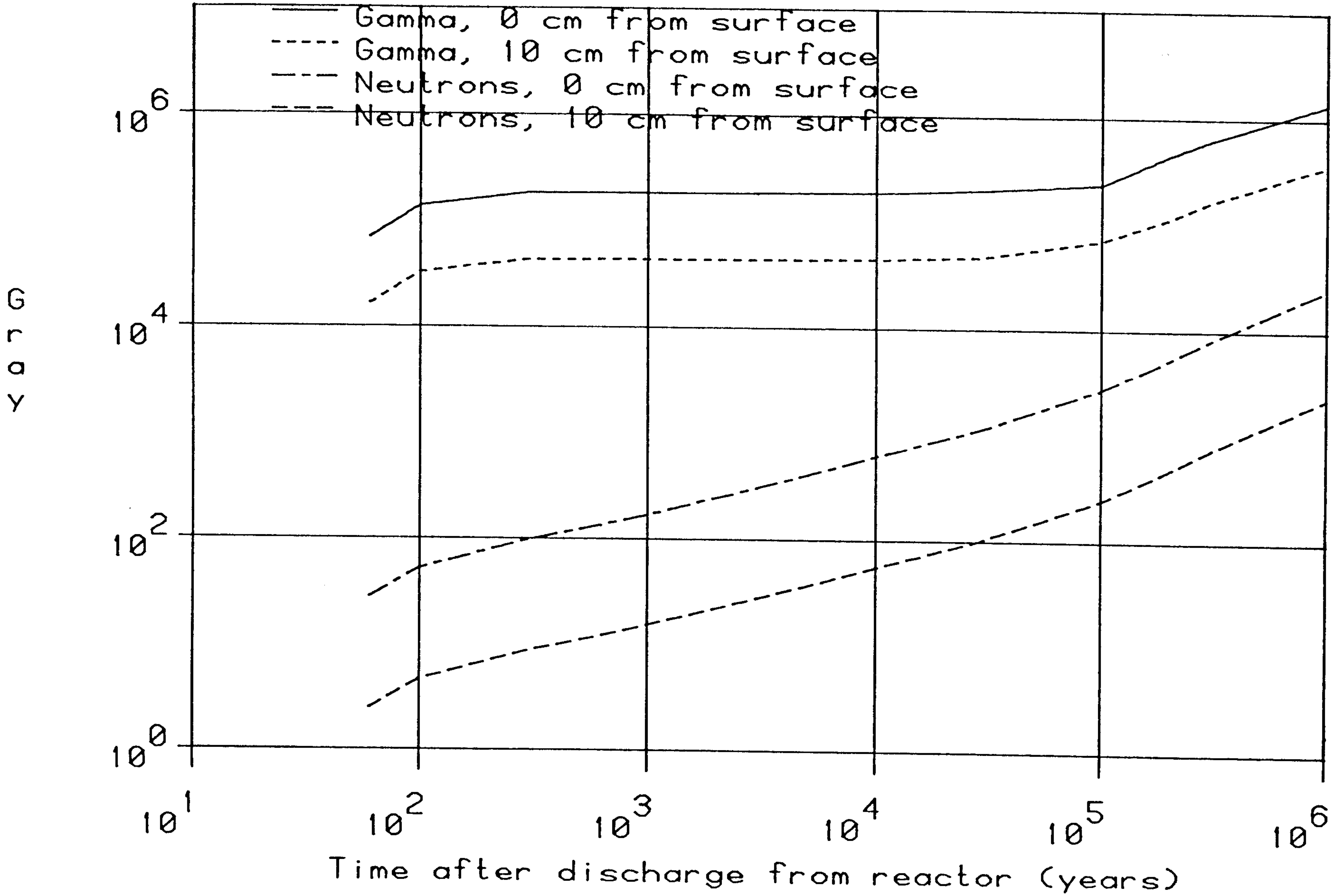

Fig 17 Accumulated dose to water outside a capsule
KBS-2 (t(Cu)=1 cm), BWR 33 MWd/kgU

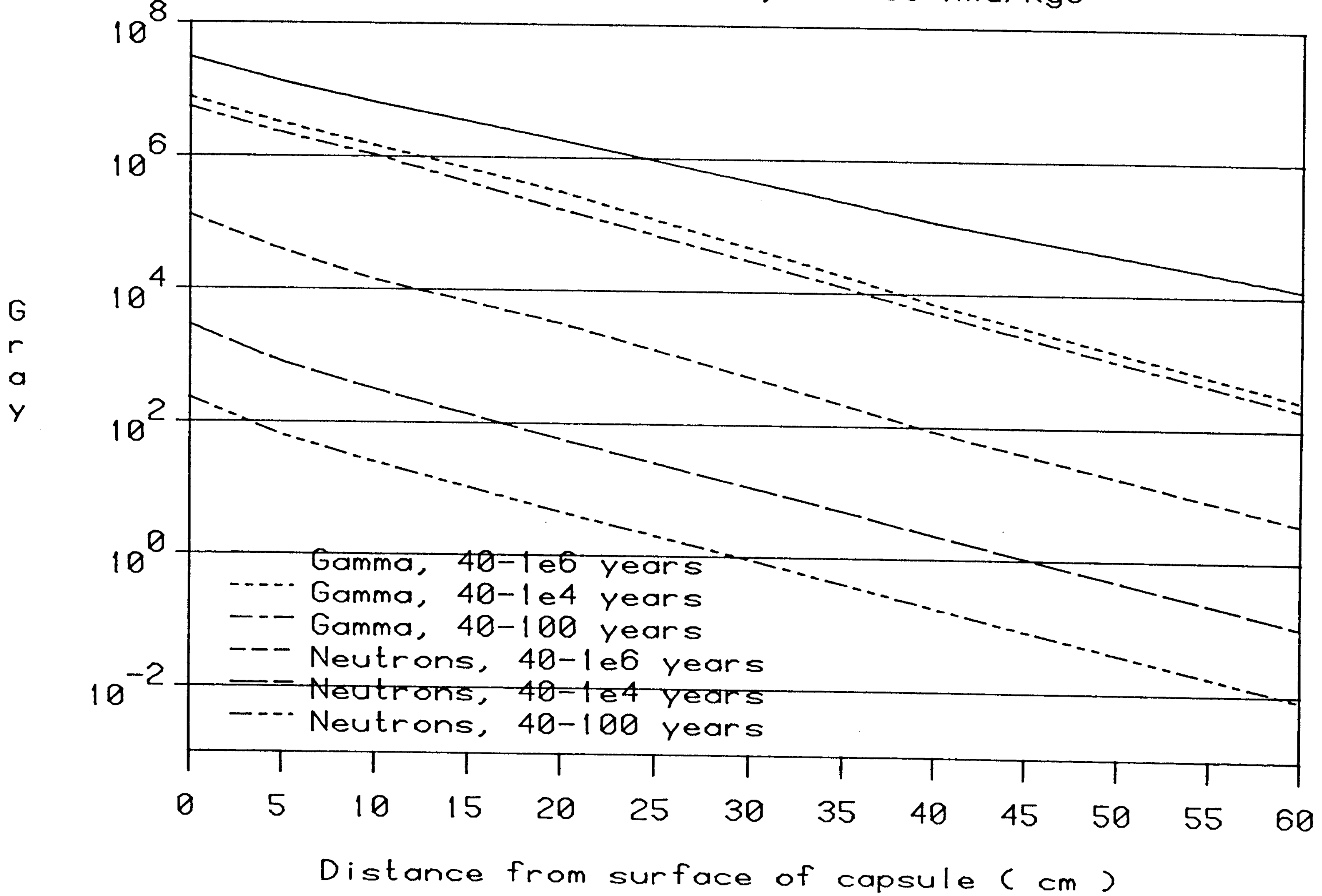

Fig 18 Accumulated dose to water outside a capsule KBS-2 (t(Cu)=10 cm), BWR 33 MWd/kgU

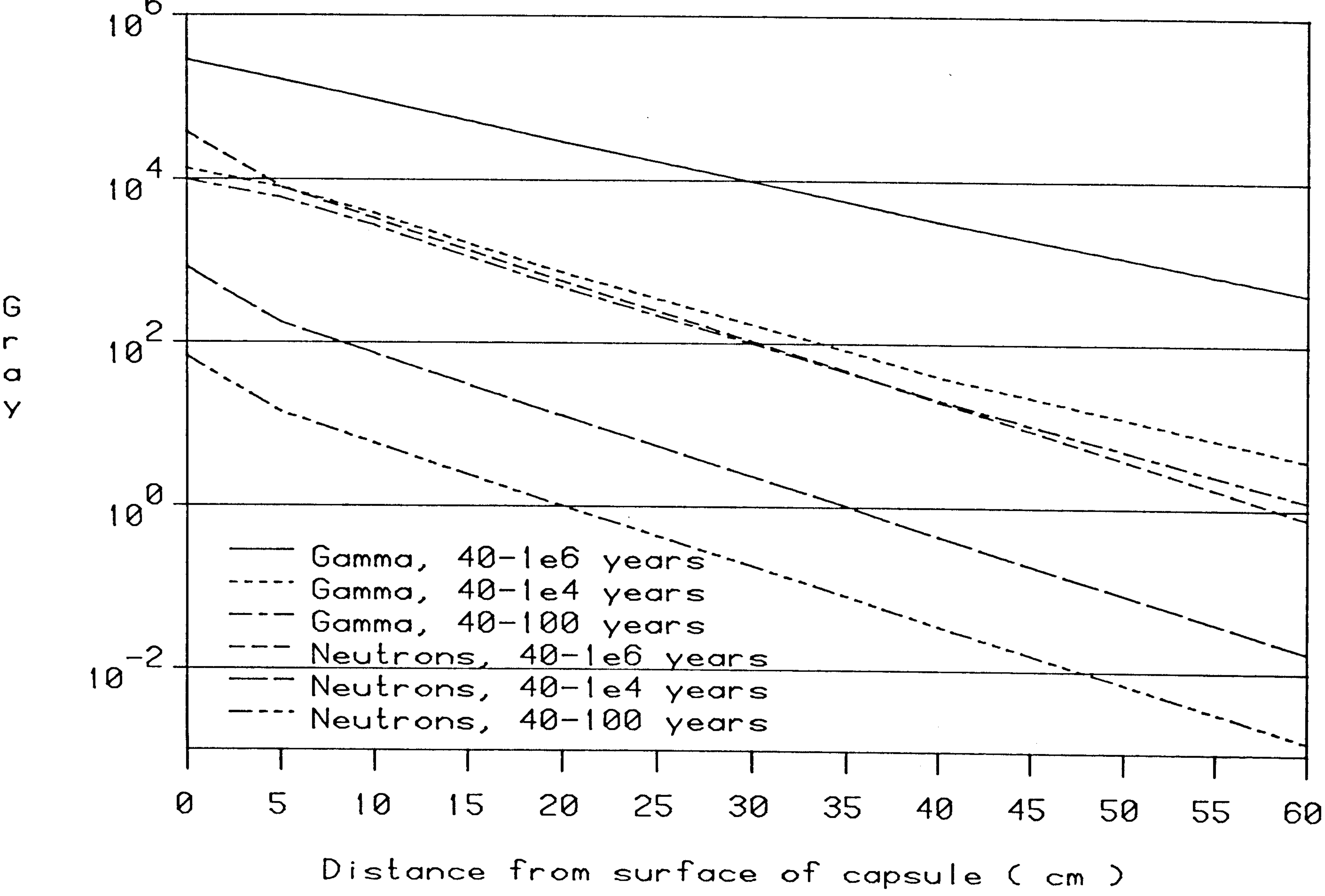

Fig 19 Accumulated dose to water outside a capsule KBS-2 (t(Cu)=20 cm), BWR 33 MWd/kgU

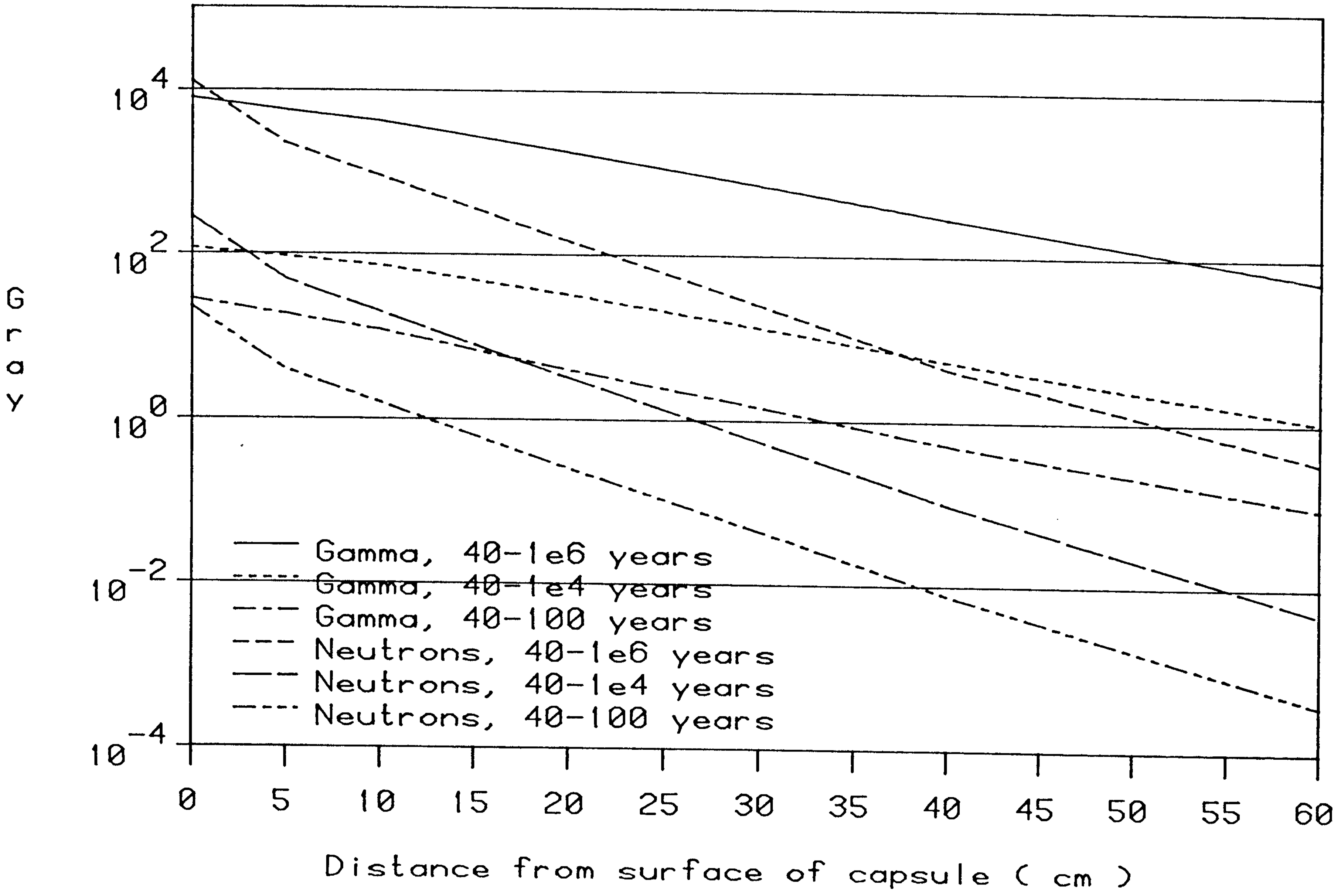

Fig 20 Accumulated dose to water outside a capsule KBS-2 (t(Cu)=10 cm), PWR 33 MWd/kgU

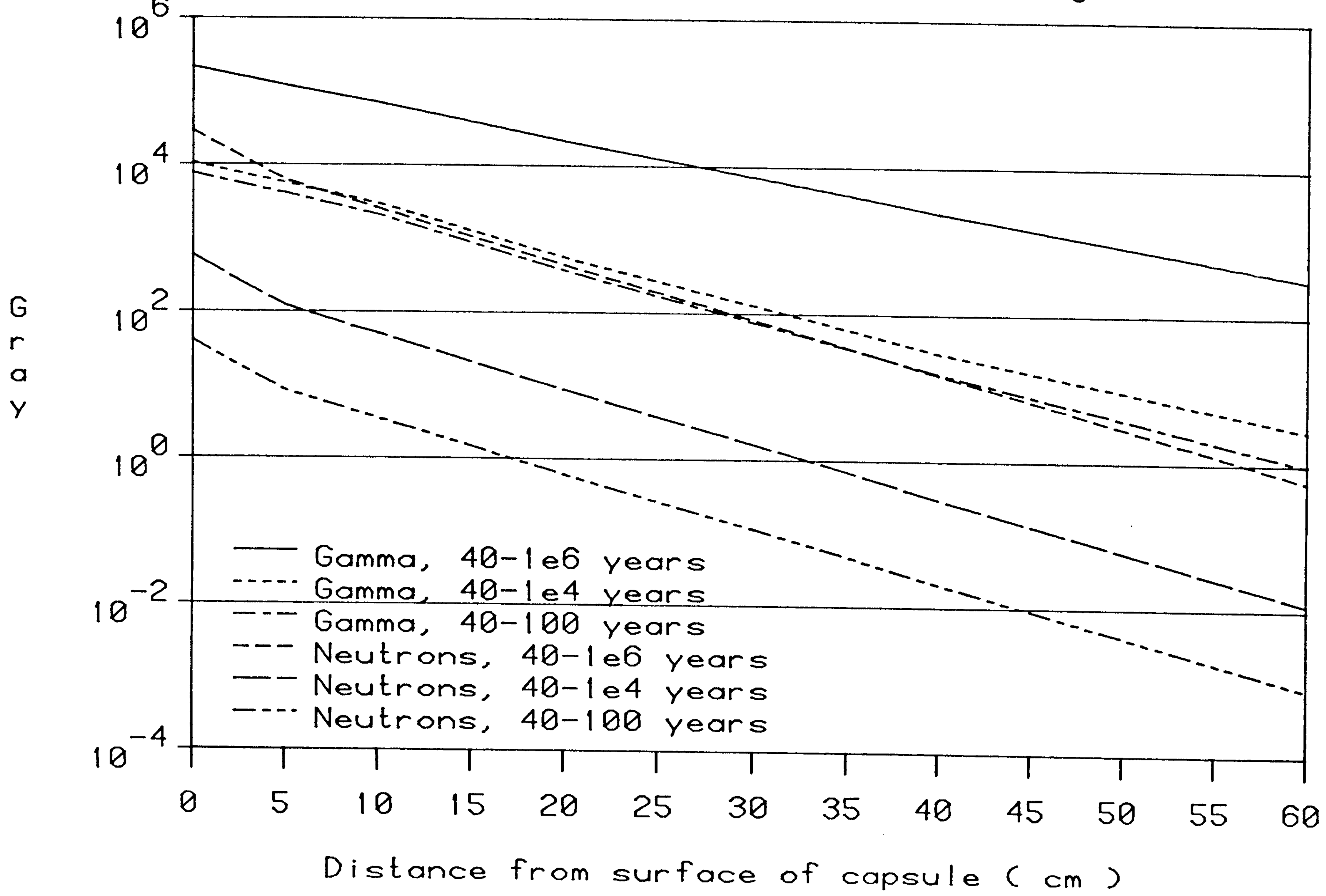

Fig 21 Accumulated dose to water outside a capsule KBS-2 (t(Cu)=10 cm), PWR 38 MWd/kgU

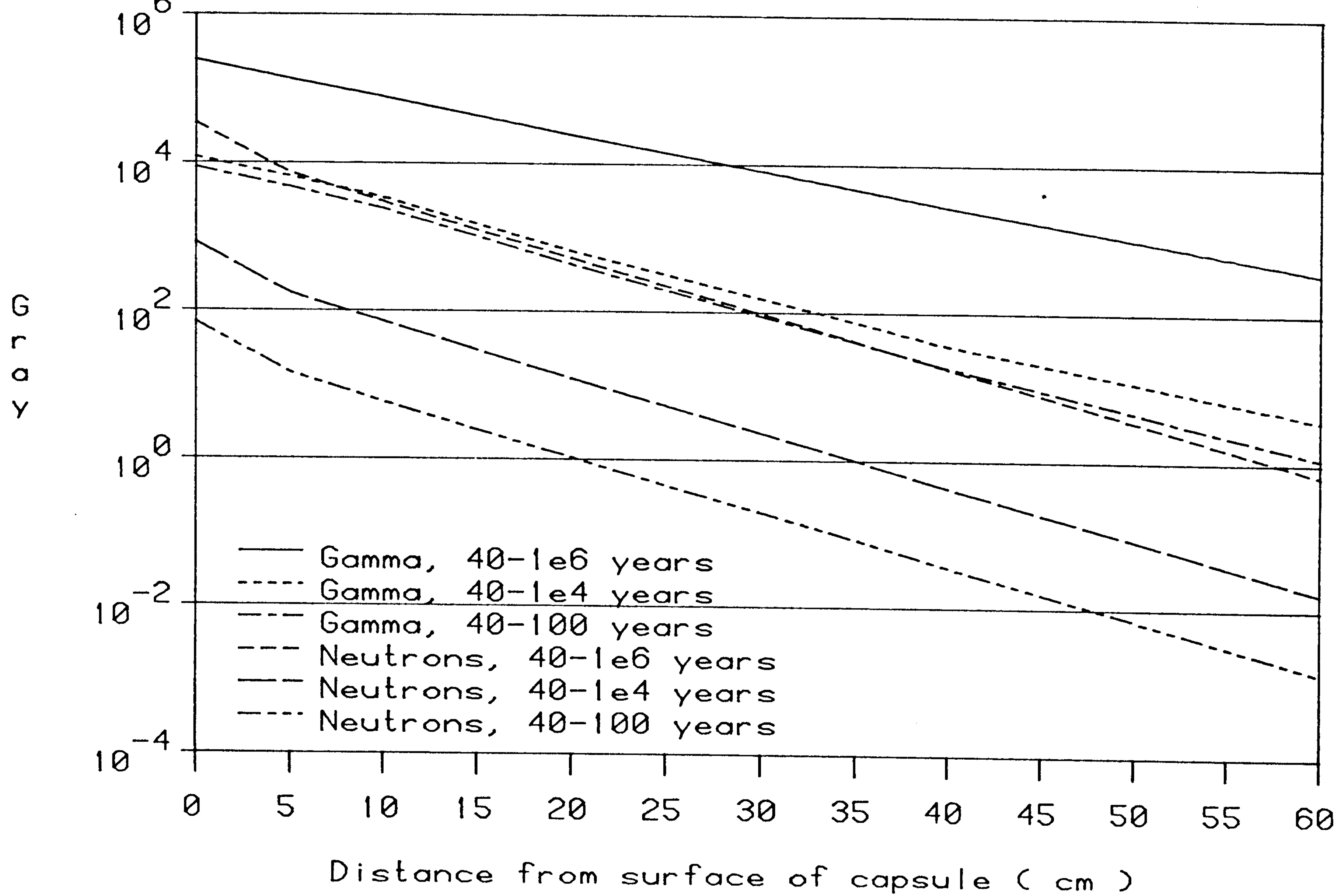

Fig 22 Accumulated dose to water outside a capsule KBS-2 (t(Cu)=10 cm), PWR 45 MWd/kgU

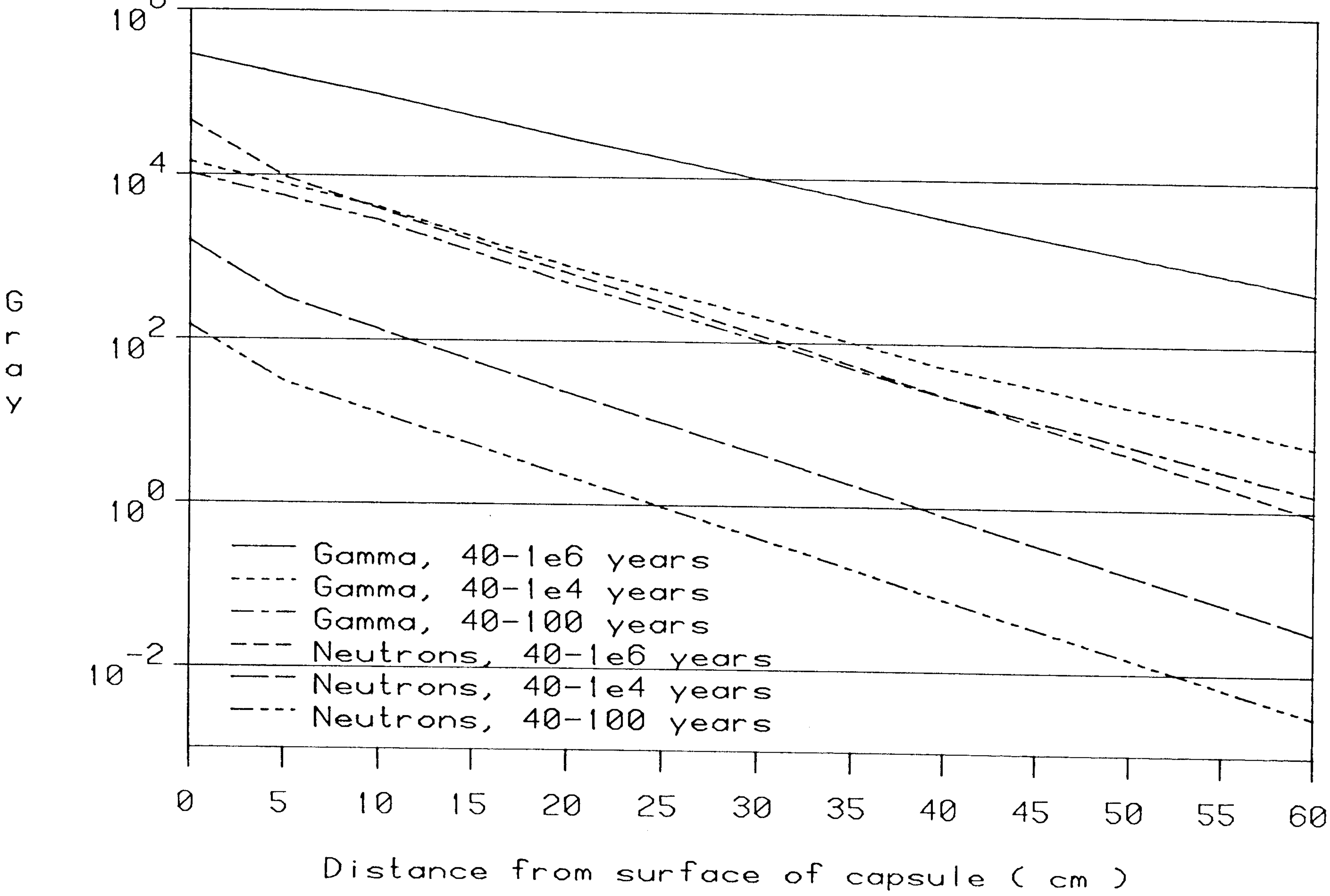

Fig 23 Accumulated dose to water outside a capsule KBS-3 (t(Cu)=6 cm), BWR 33 MWd/kgU

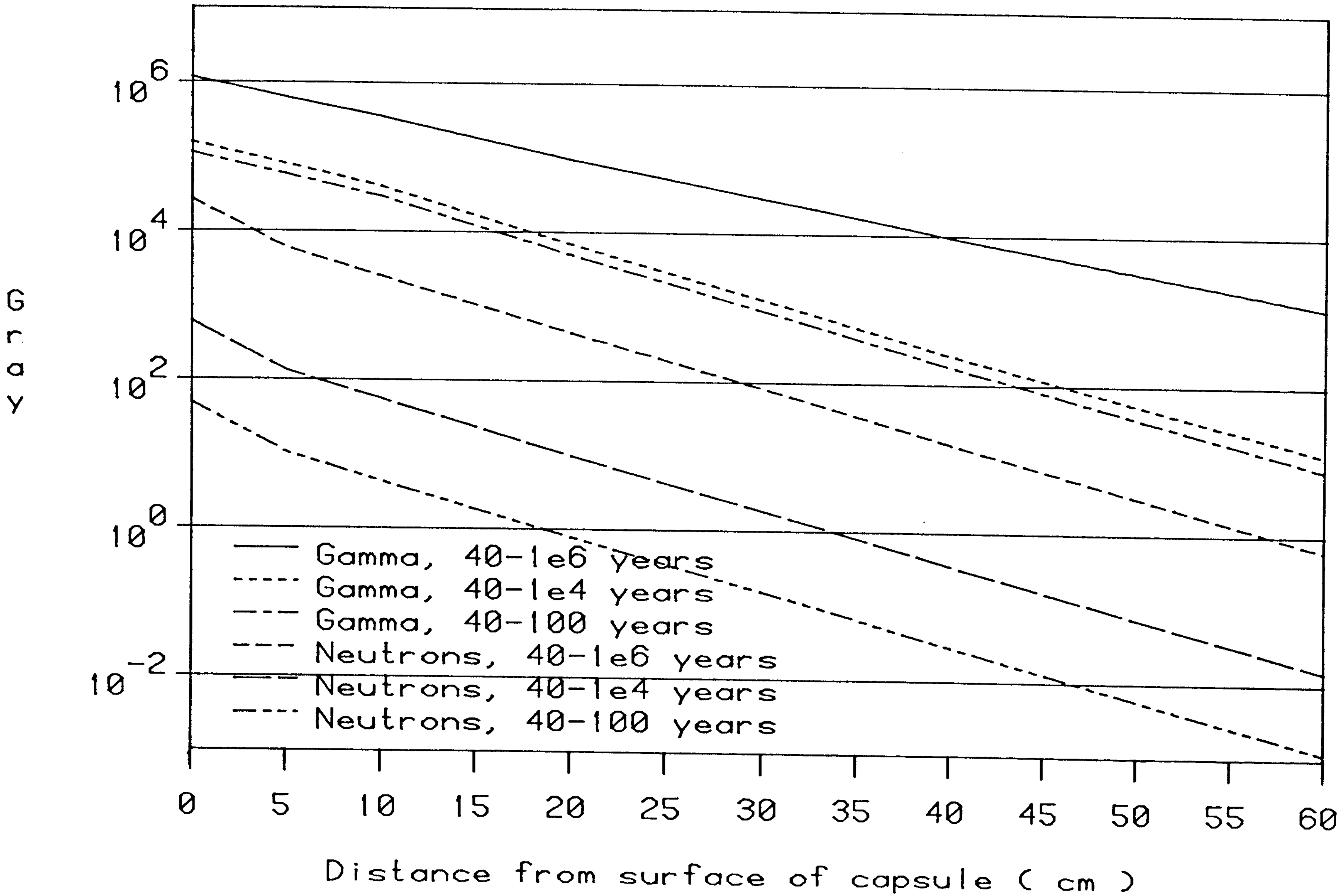

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Fig 24 Accumulated dose to water outside a capsule KBS-3 (t(Cu)=6 cm), PWR 38 MWd/kgU

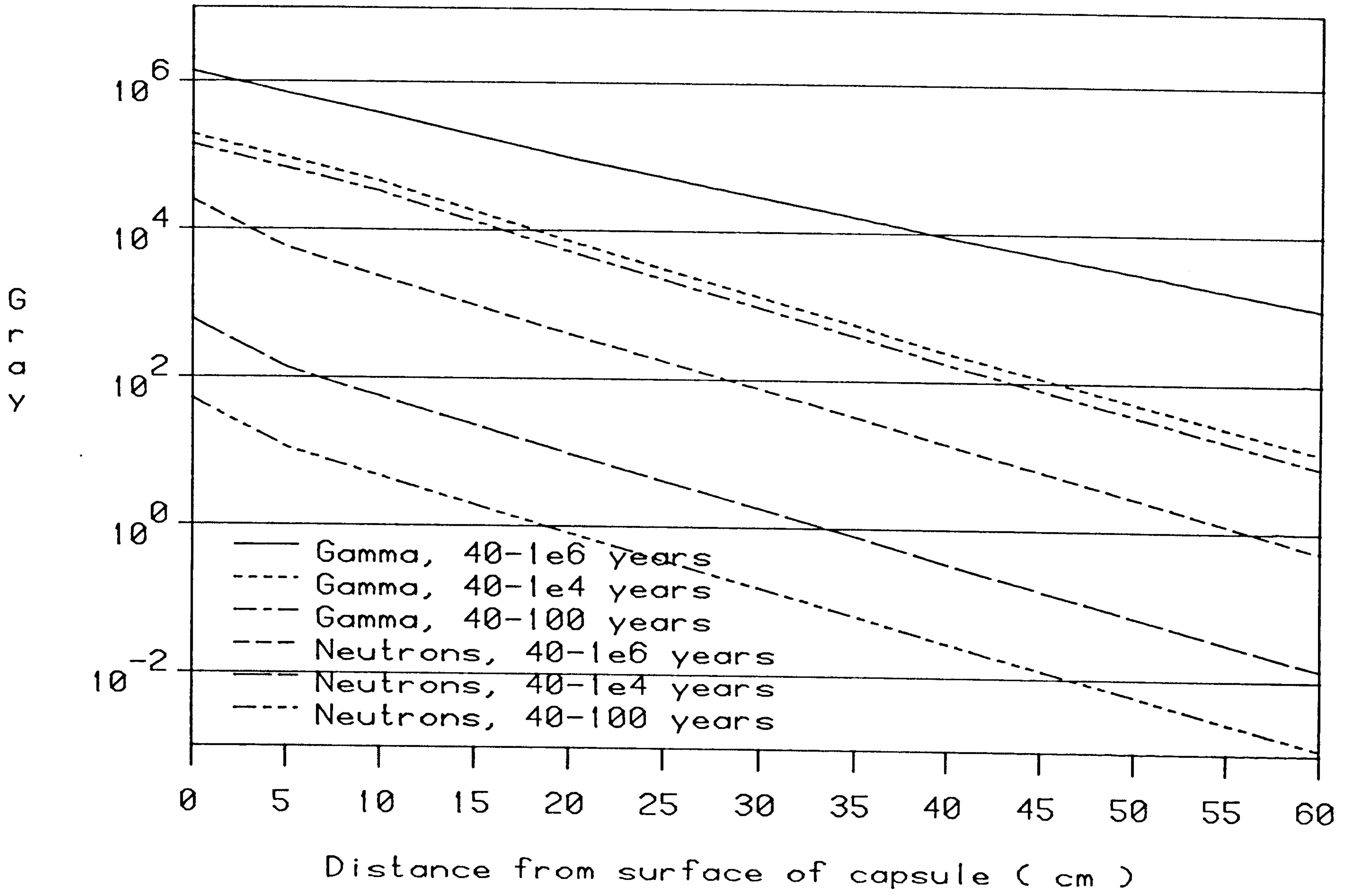


Fig 25 Energy deposition to water outside a capsule KBS-2 (t(Cu)=1 cm), BWR 33 MWd/kgU

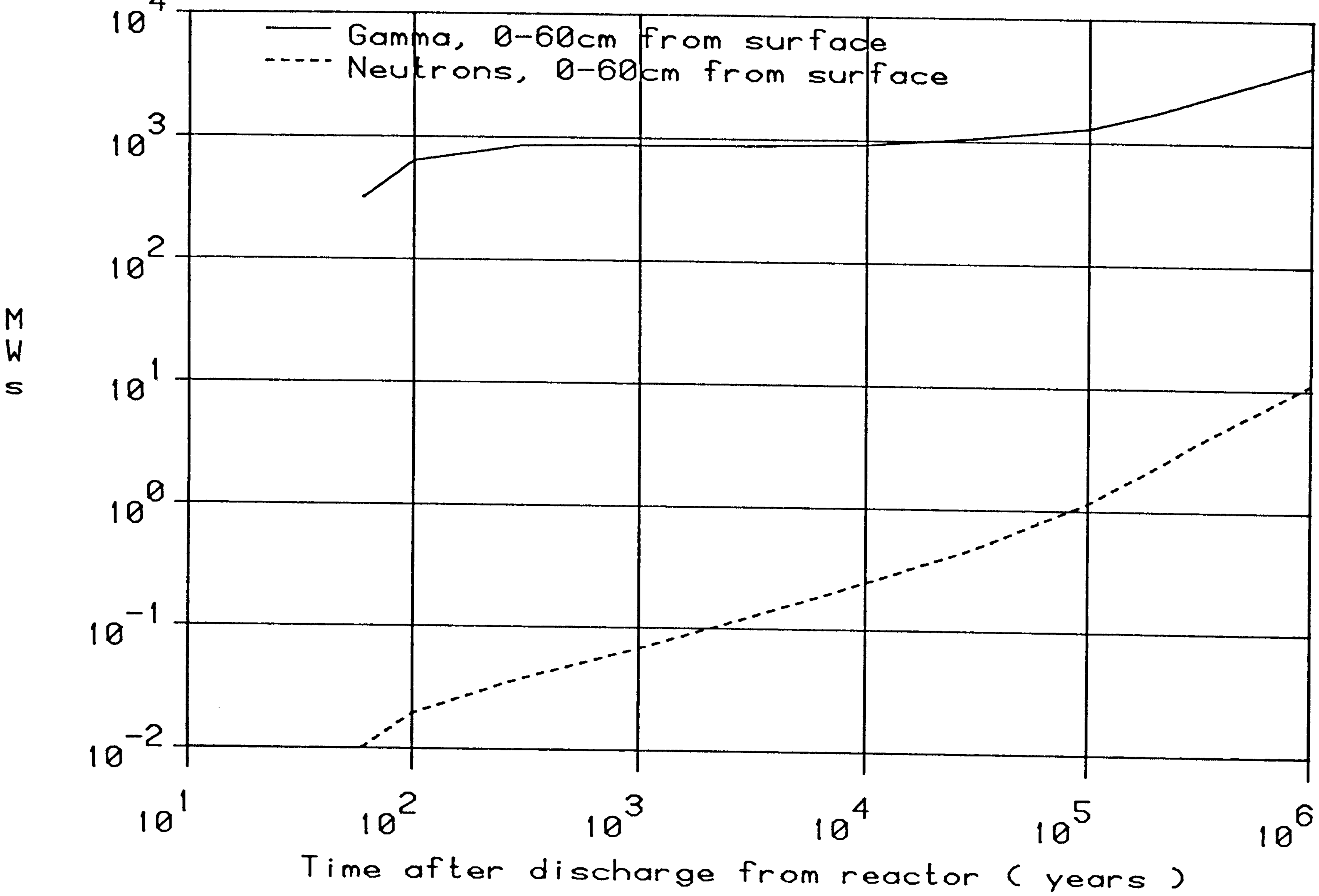


Fig 26 Energy deposition to water outside a capsule KBS-2 (t(Cu)=10 cm), BWR 33 MWd/kgU

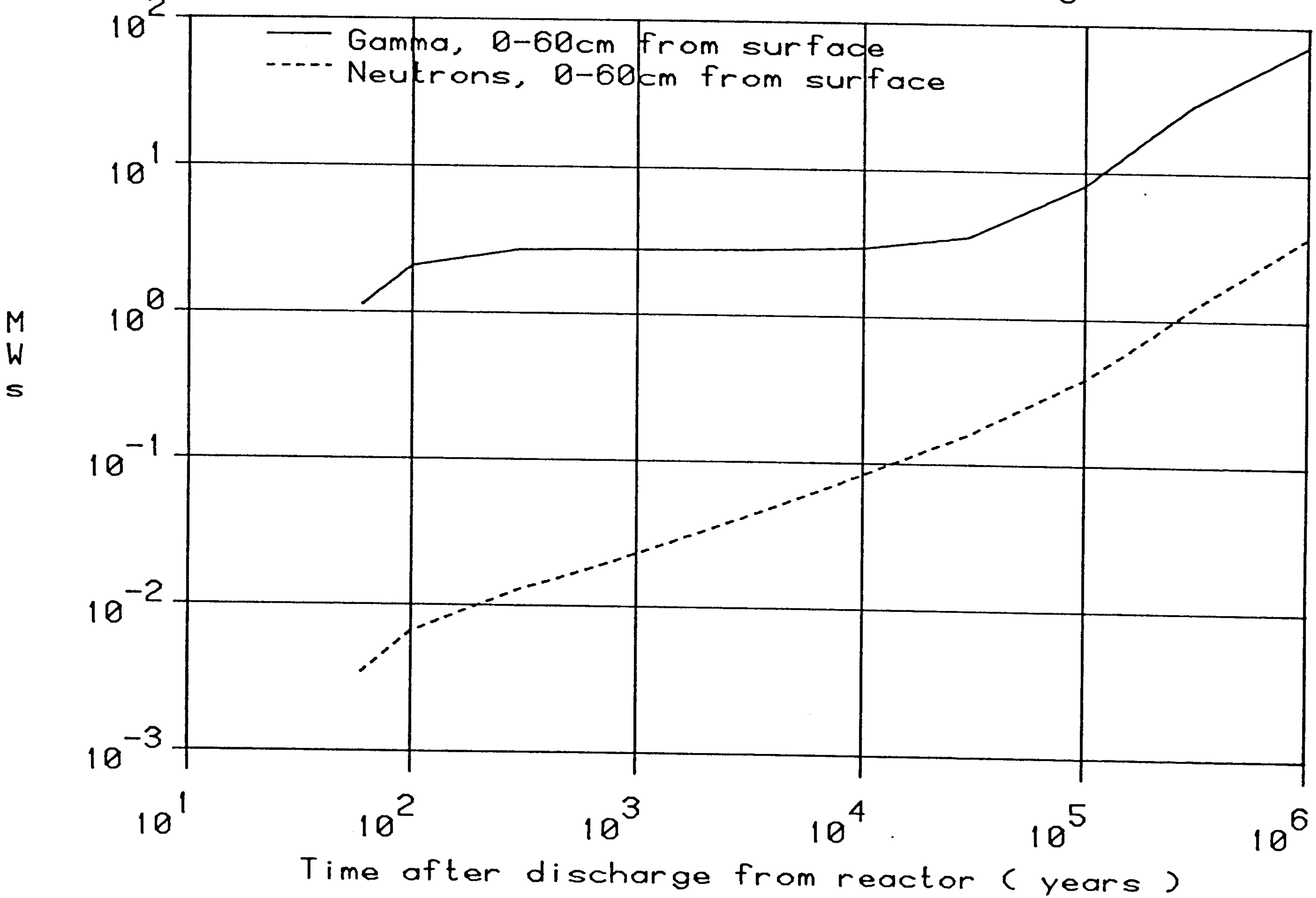


Fig 27 Energy deposition to water outside a capsule KBS-2 (t(Cu)=20 cm), BWR 33 MWd/kgU

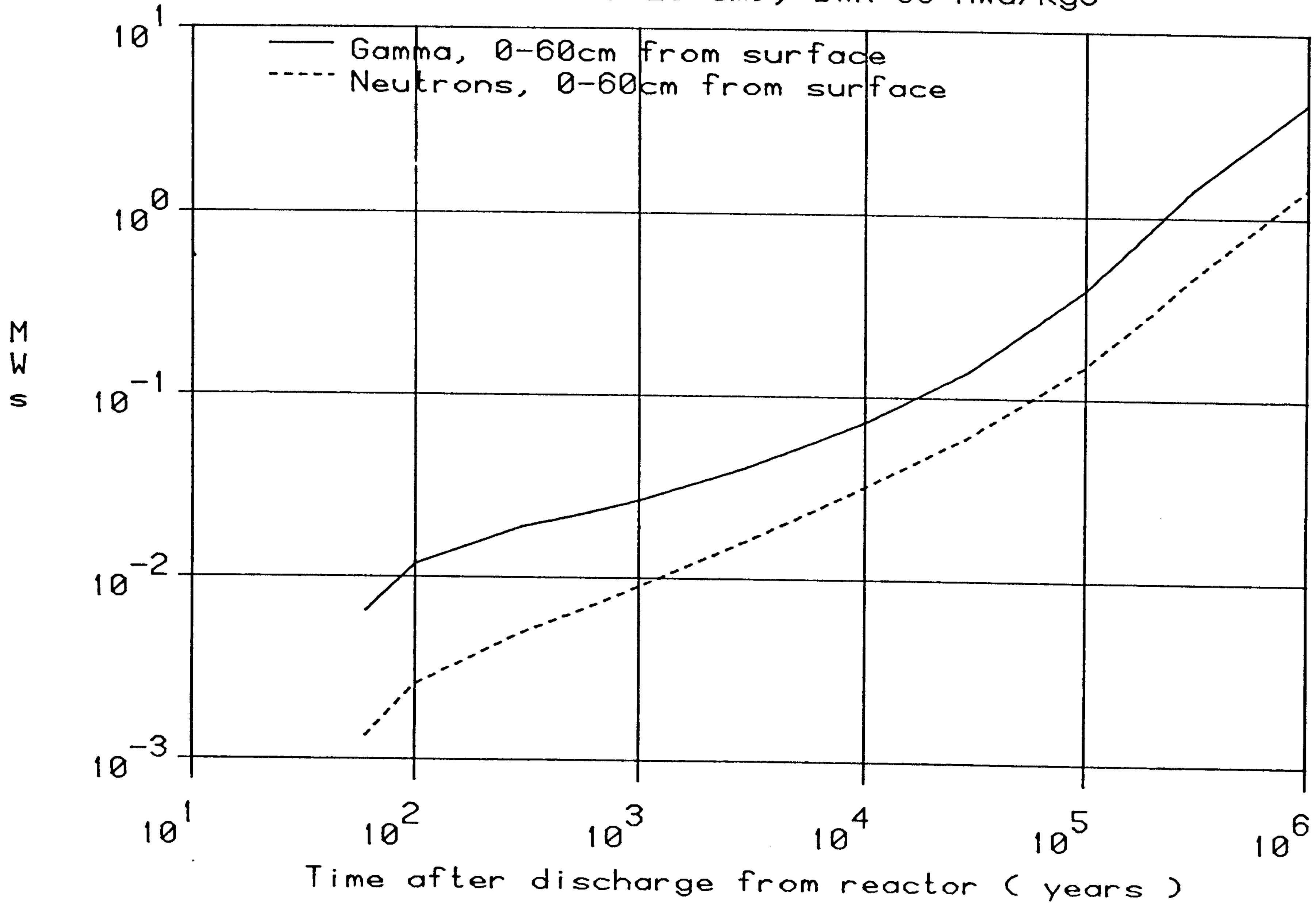


Fig 28 Energy deposition to water outside a capsule KBS-2 (t(Cu)=10 cm), PWR 33 MWd/kgU

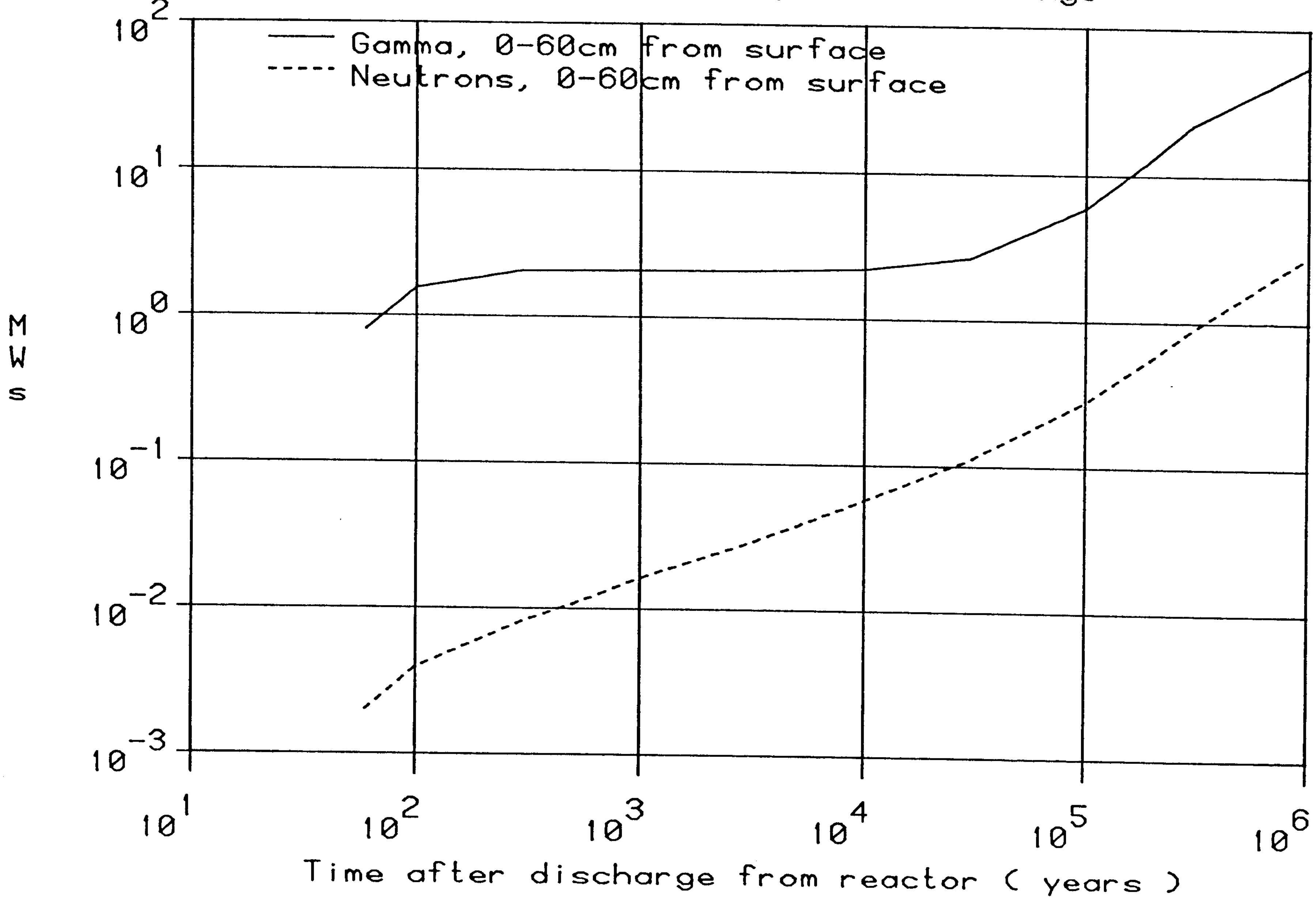


Fig 29 Energy deposition to water outside a capsule KBS-2 (t(Cu)=10 cm), PWR 38 MWd/kgU

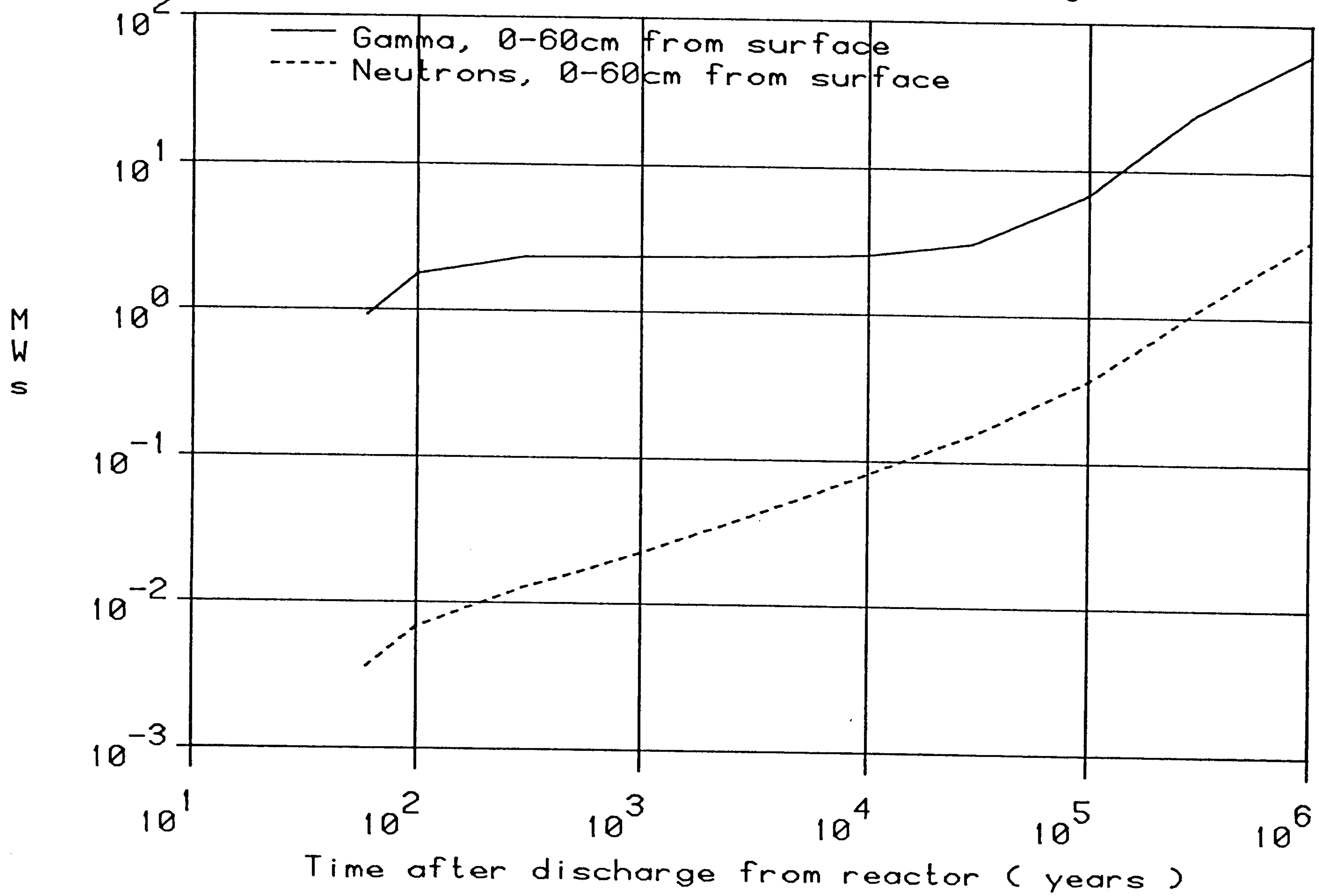


Fig 30 Energy deposition to water outside a capsule KBS-2 (t(Cu)=10 cm), PWR 45 MWd/kgU

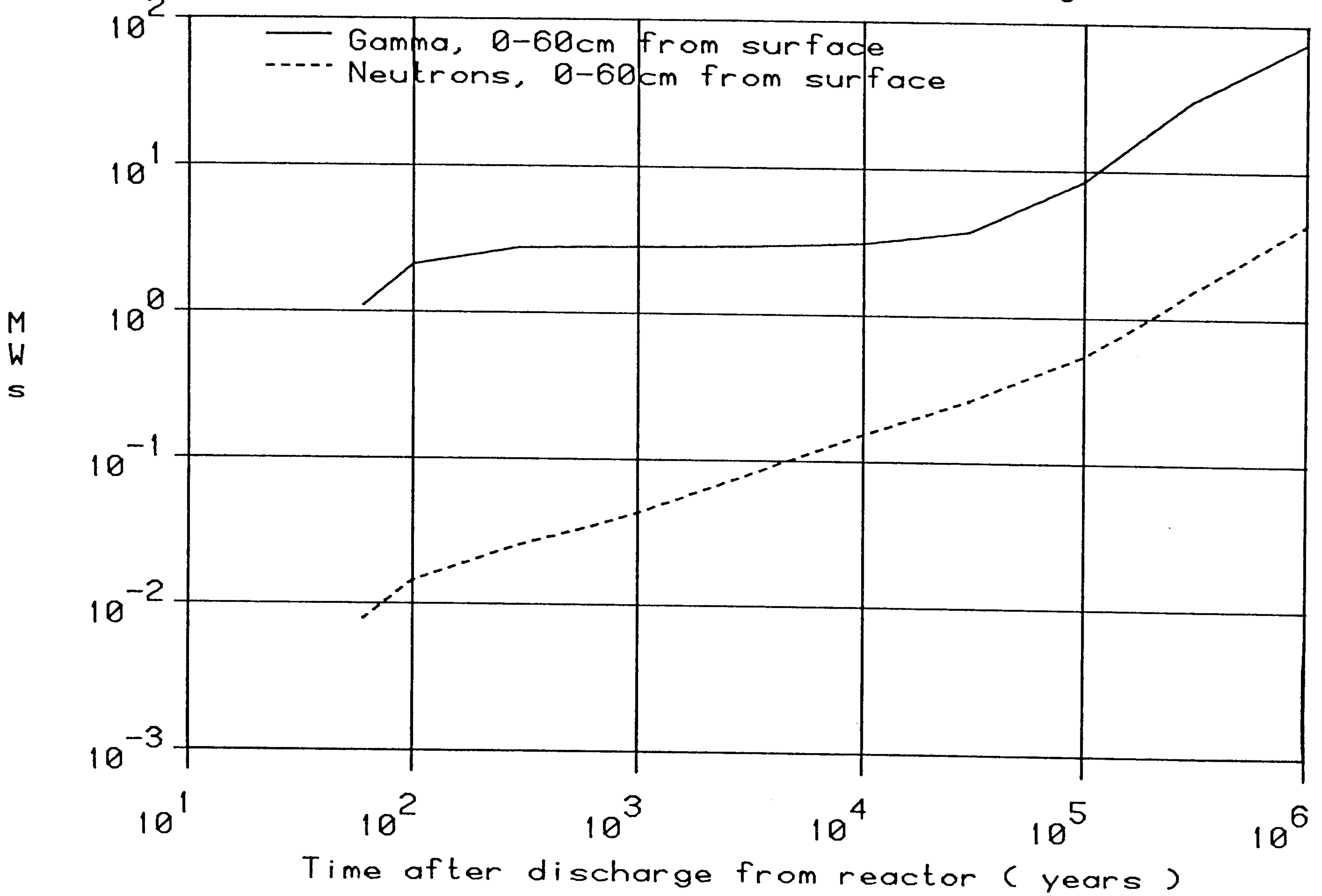


Fig 31 Energy deposition to water outside a capsule KBS-3 (t(Cu)=6 cm), BWR 33 MWd/kgU

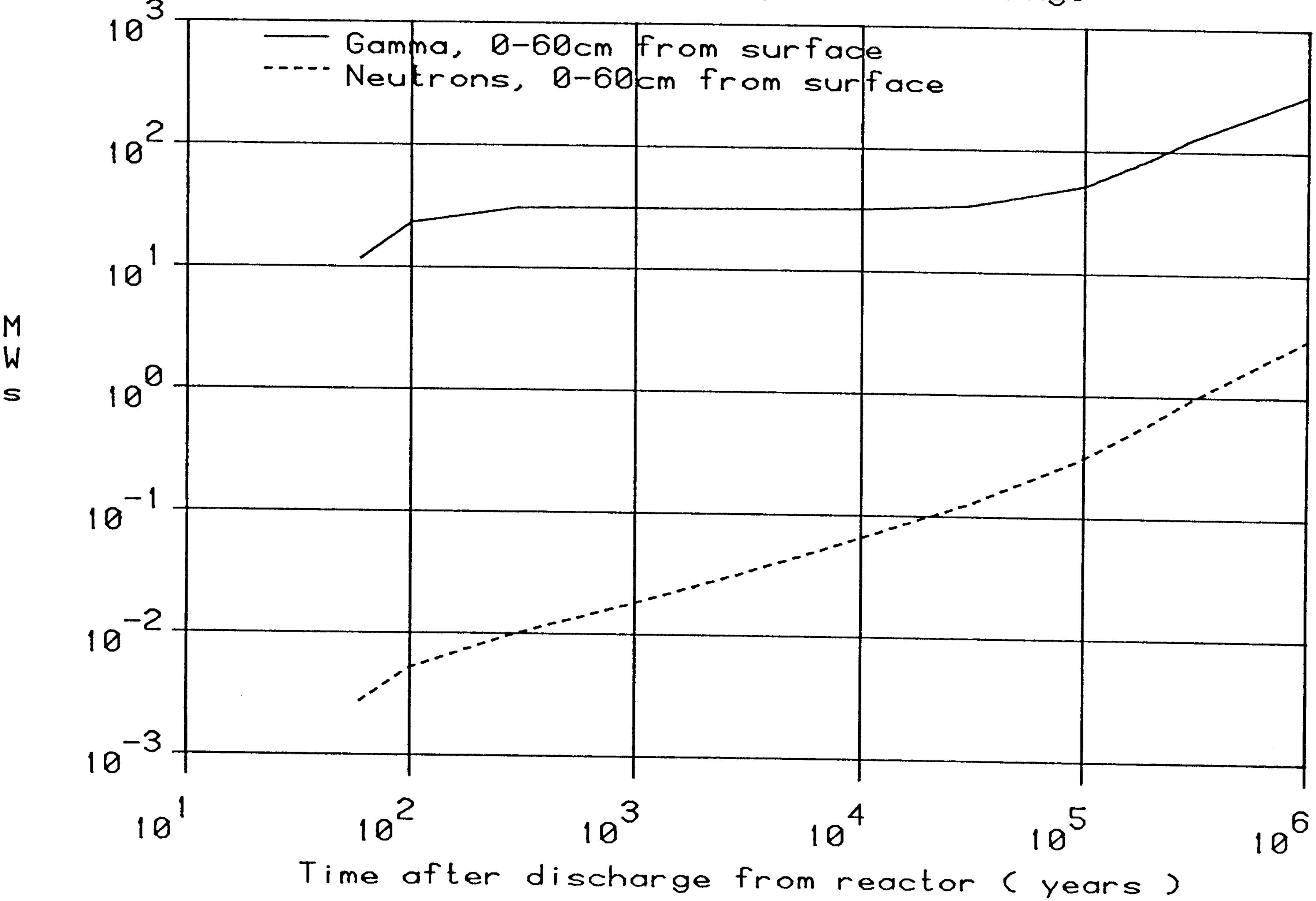
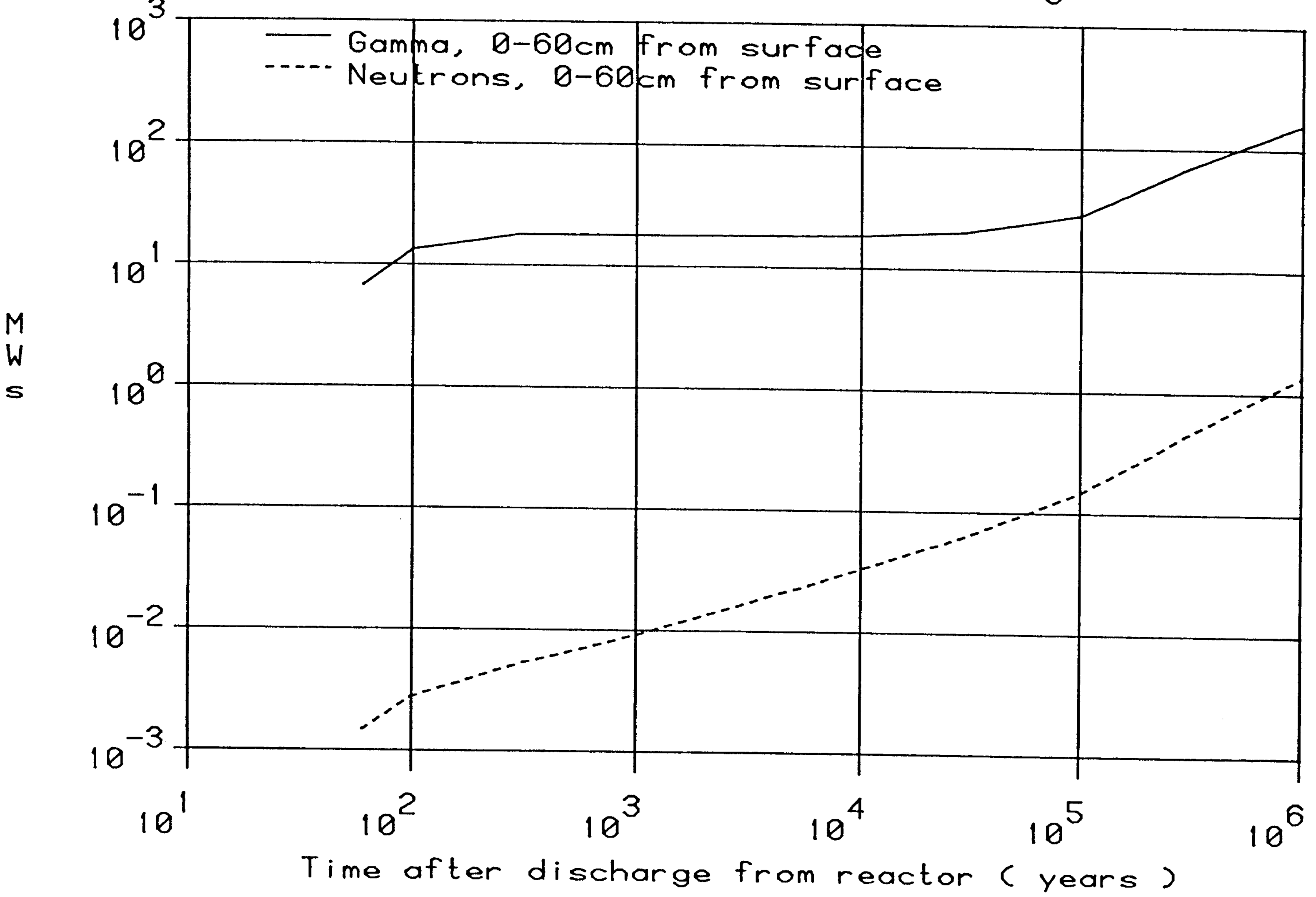


Fig 32 Energy deposition to water outside a capsule KBS-3 (t(Cu)=6 cm), PWR 38 MWd/kgU



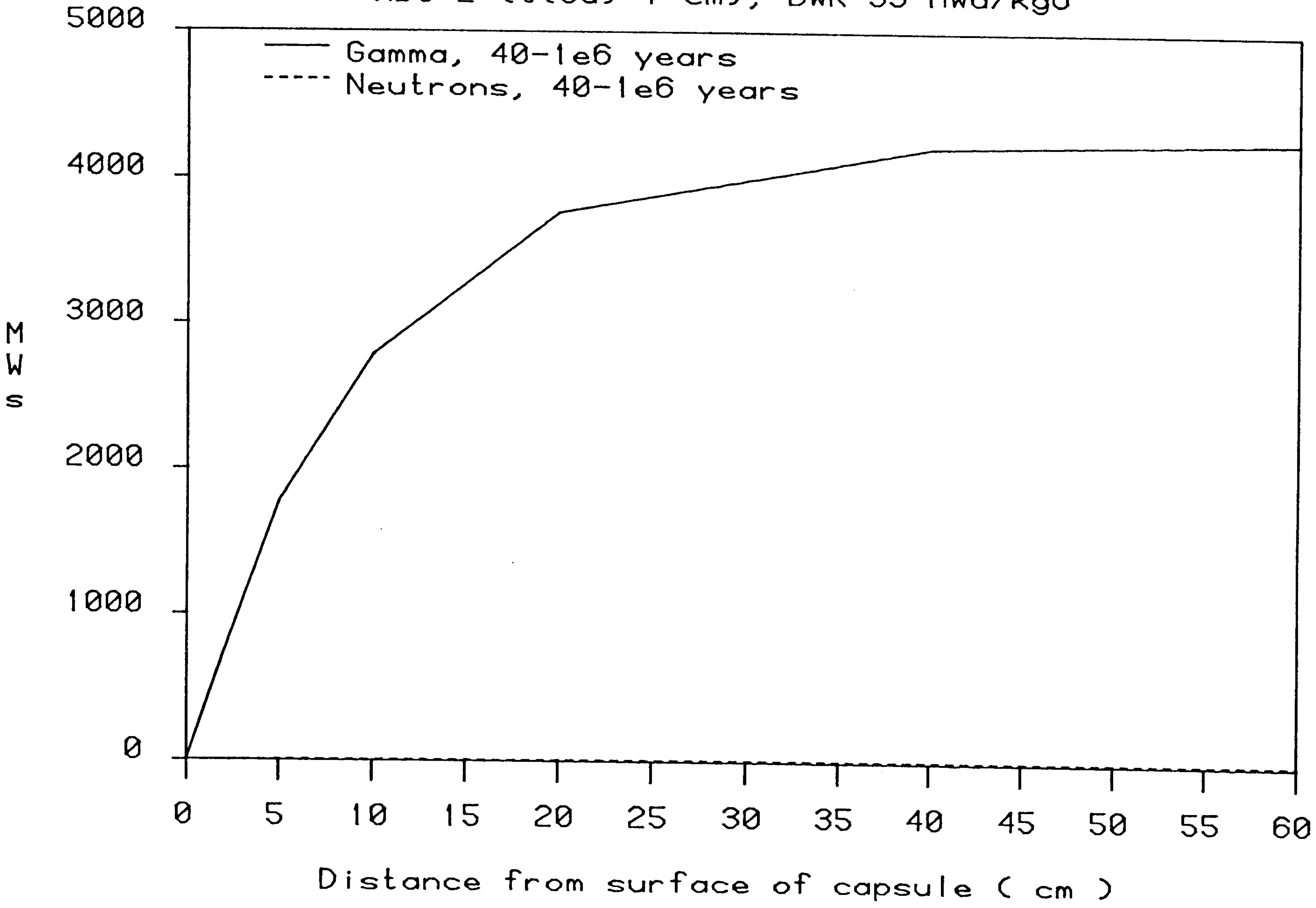


Fig 33 Energy deposition to water outside a capsule KBS-2 (t(Cu)=1 cm), BWR 33 MWd/kgU

Fig 34 Energy deposition to water outside a capsule KBS-2 (t(Cu)=10 cm), BWR 33 MWd/kgU

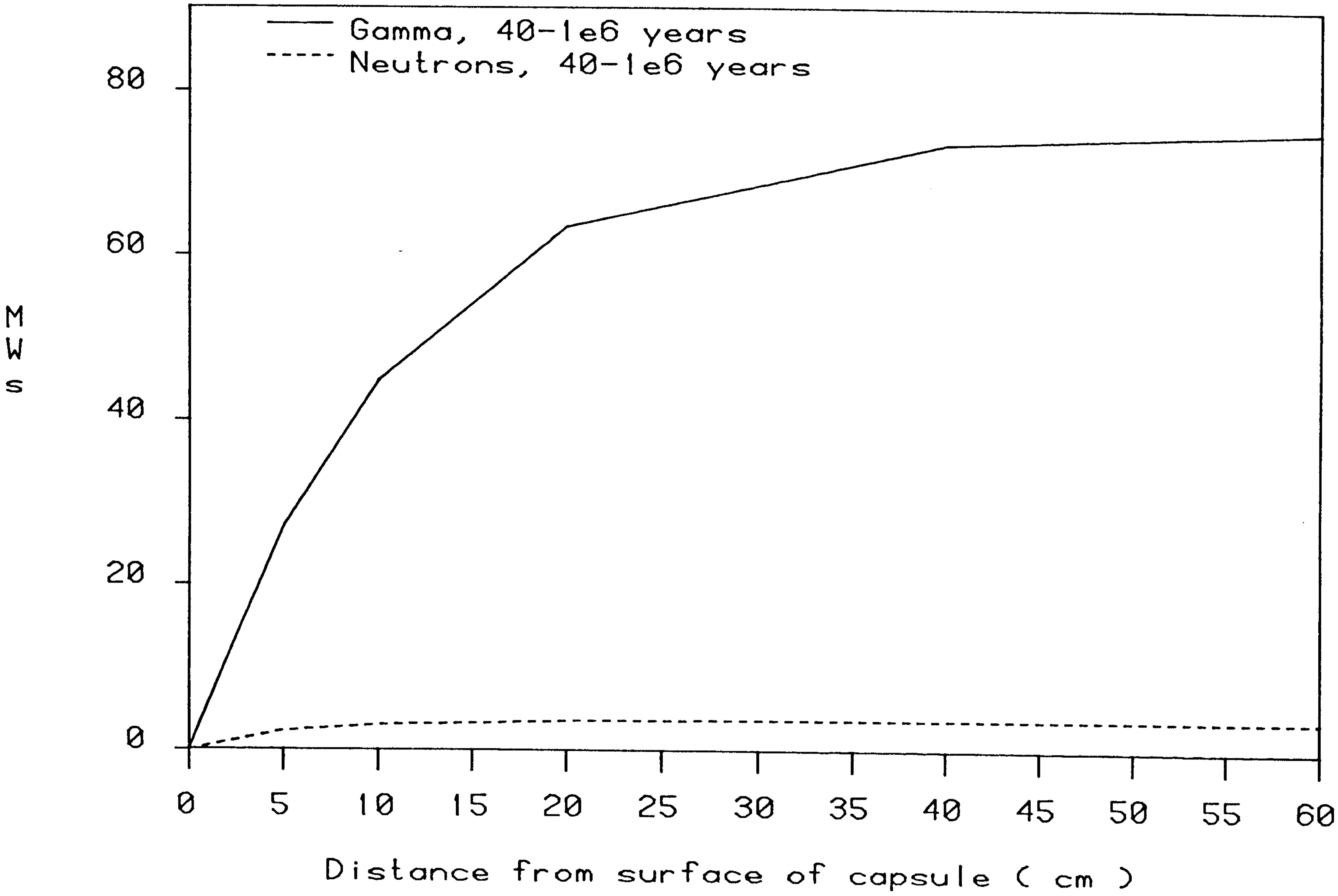


Fig 35 Energy deposition to water outside a capsule
KBS-2 (t(Cu)=20 cm), BWR 33 MWd/kgU

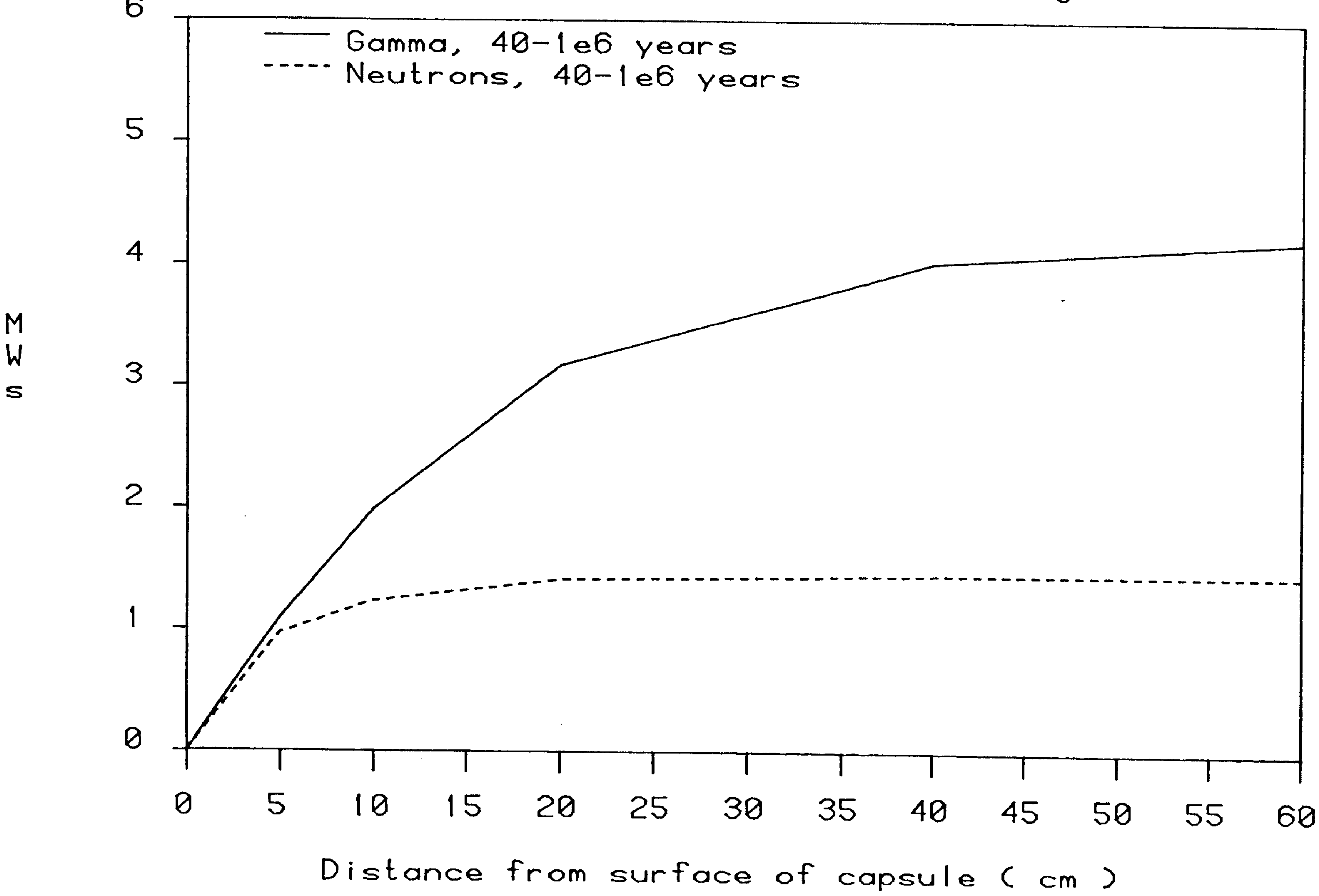


Fig 39 Energy deposition to water outside a capsule
KBS-2 (t(Cu)=10 cm), PWR 33 MWd/kgU

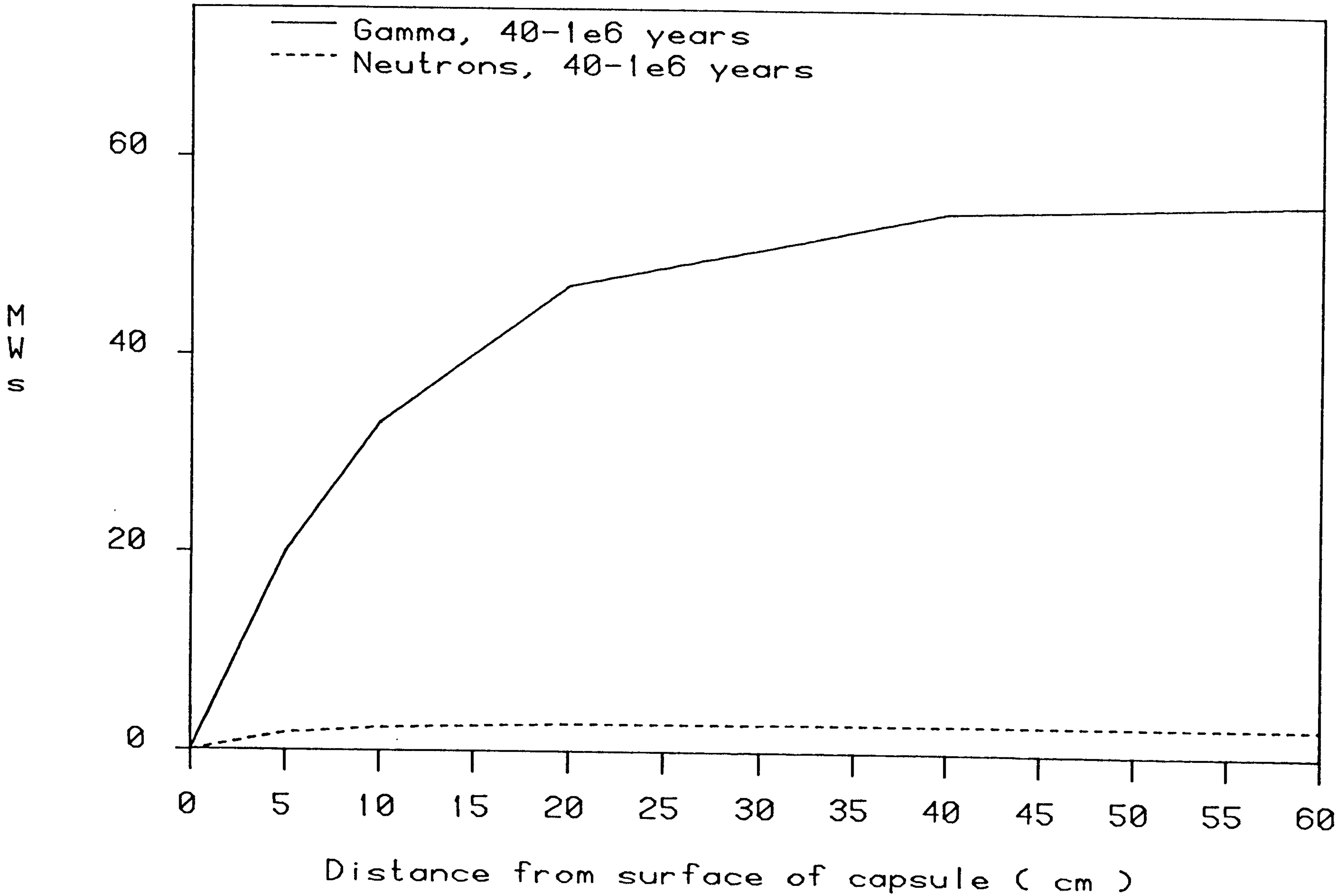


Fig 37 Energy deposition to water outside a capsule
KBS-2 (t(Cu)=10 cm), PWR 38 MWd/kgU

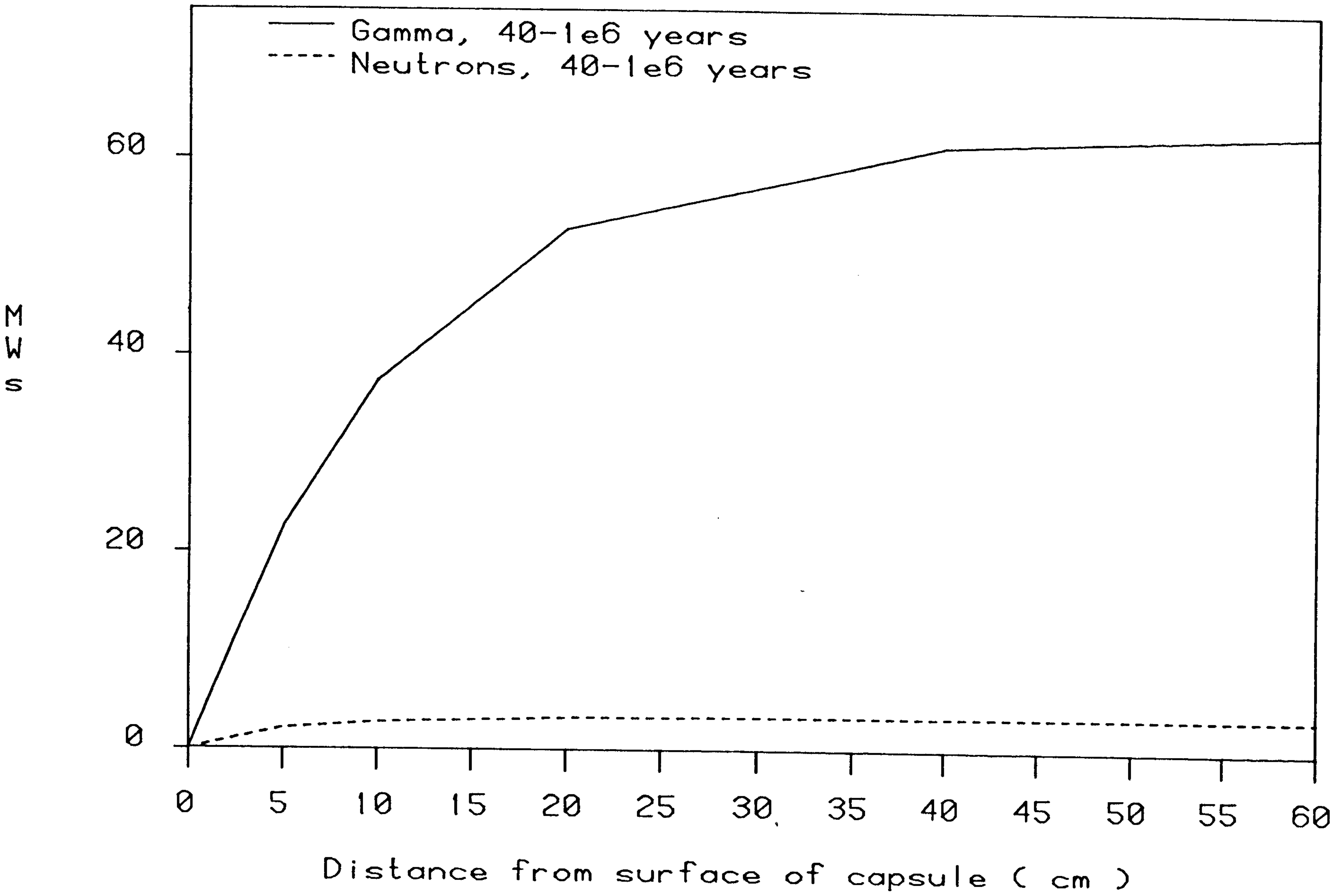


Fig 38 Energy deposition to water outside a capsule KBS-2 (t(Cu)=10 cm), PWR 45 MWd/kgU

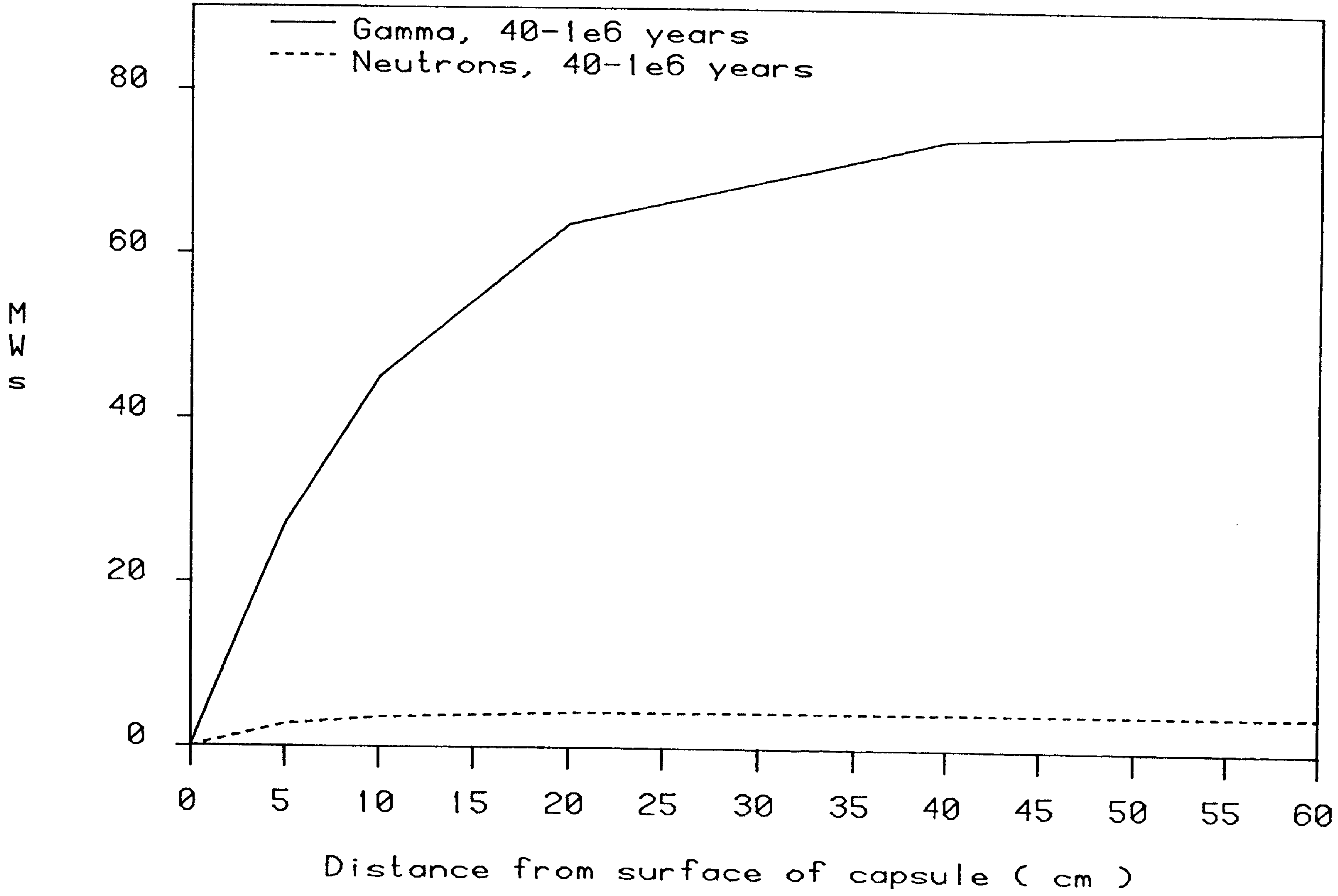


Fig 39 Energy deposition to water outside a capsule KBS-3 (t(Cu)=6 cm), BWR 33 MWd/kgU

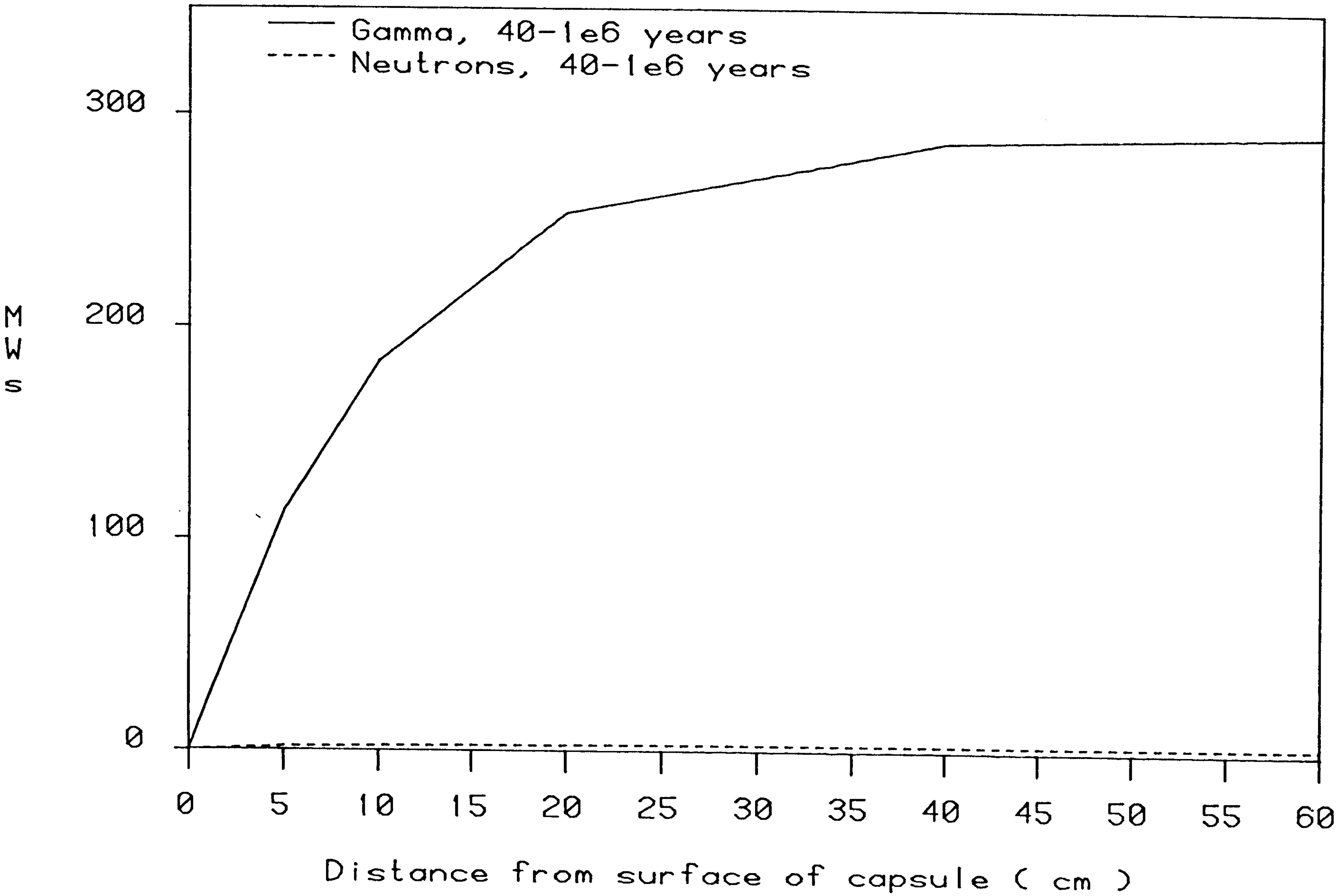
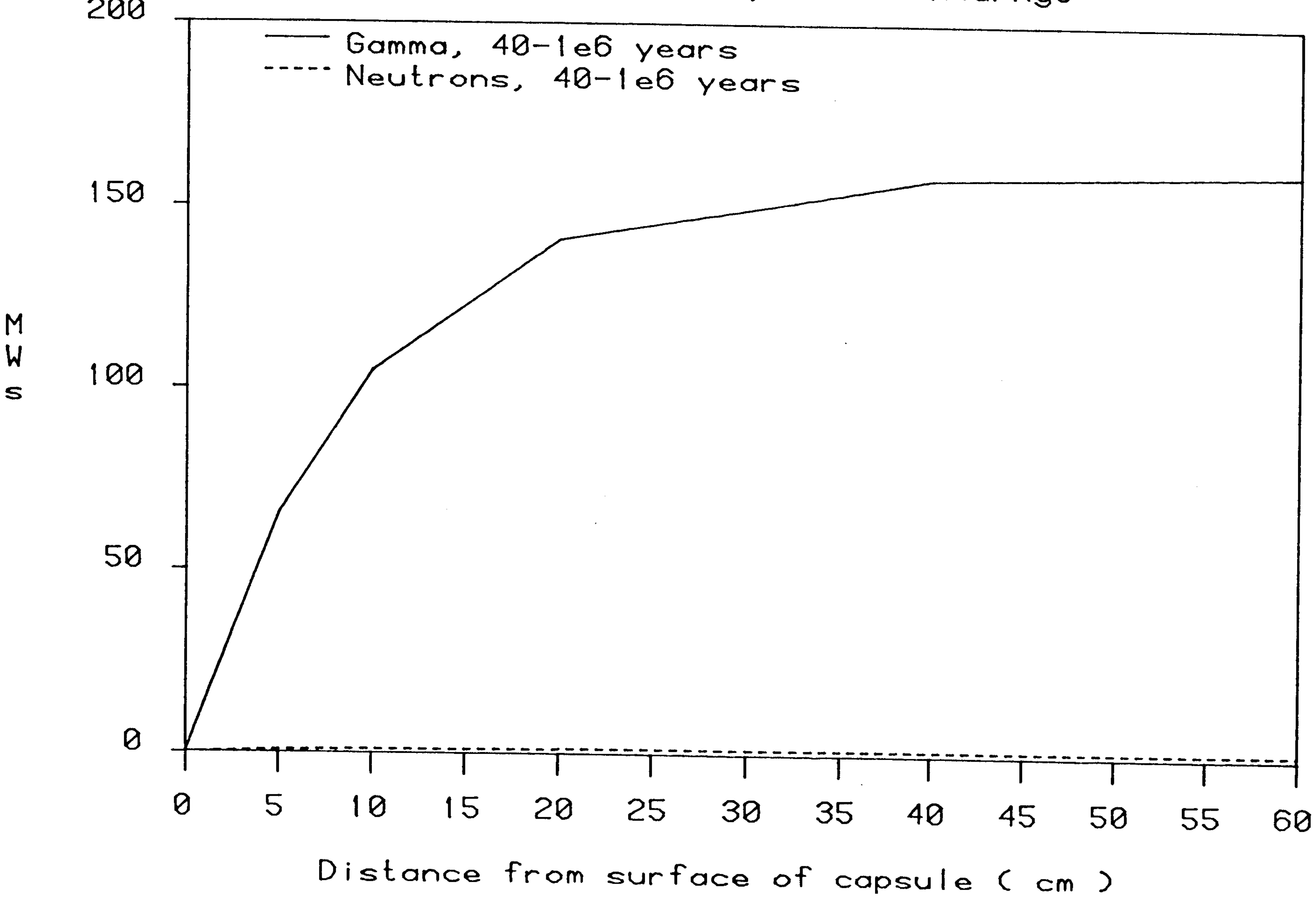


Fig 40 Energy deposition to water outside a capsule
KBS-3 (t(Cu)=6 cm), PWR 38 MWd/kgU



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

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

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

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

1982

TR 82-01	Hydrothermal conditions around a radioactive waste repository Part 3 - Numerical solutions for anisotropy Roger Thunvik Royal Institute of Technology, Stockholm, Sweden Carol Braester Institute of Technology, Haifa, Israel December 1981
TR 82-02	Radiolysis of groundwater from HLW stored in copper canisters Hilbert Christensen Erling Bjergbakke Studsvik Energiteknik AB, 1982-06-29

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Some calculated results obtained from a model based on the concept of stratified flow and matrix diffusion
Ivars Neretnieks
Royal Institute of Technology
Department of Chemical Engineering
Stockholm, Sweden, October 1981

TR 82-04 Radionuclide chain migration in fissured rock -
The influence of matrix diffusion
Anders Rasmuson *
Akke Bengtsson **
Bertil Grundfelt **
Ivars Neretnieks *
April, 1982

* Royal Institute of Technology
Department of Chemical Engineering
Stockholm, Sweden

** KEMAKTA Consultant Company
Stockholm, Sweden

TR 82-05 Migration of radionuclides in fissured rock -
Results obtained from a model based on the concepts of hydrodynamic dispersion and matrix diffusion
Anders Rasmuson
Ivars Neretnieks
Royal Institute of Technology
Department of Chemical Engineering
Stockholm, Sweden, May 1982

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Calculation of rock permeability
Carol Braester
Israel Institute of Technology, Haifa, Israel
Roger Thunvik
Royal Institute of Technology
Stockholm, Sweden, June 1982

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Roland Pusch
Division Soil Mechanics, University of Luleå
Luleå, Sweden, 1982-06-30

TR 82-08 Diffusion in the matrix of granitic rock
Field test in the Stripa mine
Part 1
Lars Birgersson
Ivars Neretnieks
Royal Institute of Technology
Department of Chemical Engineering
Stockholm, Sweden, July 1982

TR 82-09:1 Radioactive waste management plan
PLAN 82
Part 1 General
Stockholm, June 1982

TR 82-09:2 Radioactive waste management plan
PLAN 82
Part 2 Facilities and costs
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TR 82-10 The hydraulic properties of fracture zones and tracer tests with non-reactive elements in Studsvik
Carl-Erik Klockars
Ove Persson
Geological Survey of Sweden, Uppsala
Ove Landström, Studsvik Energiteknik, Nyköping
Sweden, April 1982

TR 82-11 Radiation levels and absorbed doses around copper canisters containing spent LWR fuel
Klas Lundgren
Västerås, Sweden, 1982-08-11