KERNFORSCHUNGSZENTRUM

KARLSRUHE

Dezember 1972 KFK 1635

Abteilung Strahlenschutz und Sicherheit

Nuclear Accident Dosimetry Measurements at the Second I.A.E.A. Intercomparison at Oak Ridge, USA, May 1971

E. Piesch

GESELLSCHAFT
FÜR
KERNFORSCHUNG M.B.H.

KARLSRUHE

GESELLSCHAFT FÜR KERNFORSCHUNG M. B. H.
KARLSRUHE

Kernforschungszentrum Karlsruhe

Juni 1972 KFK 1635

Abteilung Strahlenschutz und Sicherheit

Nuclear Accident Dosimetry Measurements at the Second I.A.E.A. Intercomparison at Oak Ridge, USA, May 1971

E. Piesch

Gesellschaft für Kernforschung, Karlsruhe

Abstract

Teams from several countries participated in an International Intercomparison of Nuclear Accident Dosimeter Systems, organized by the I.A.E.A., in which criticality dosimeters were exposed to mixed pulses of neutron and gamma radiation from the Health Physics Research Reactor at Oak Ridge. This report gives the final results of the measurements made with the personnel dosimeter system of the Karlsruhe Nuclear Research Centre.

The dose assessment both in free air and on phantom are based on standard interpretation of the routine personnel dosimeter, of the phosphate glass dosimeter and of threshold detectors. During the experiment the dosimetric properties of a belt of polycarbonate foil were studied using the neutron-induced recoils and (n,α) reaction in the plastic foil for a detection of neutrons $>$ 1 MeV. The effect of fission neutrons on the reading of gamma dosimeters were studied on different phosphate glass dosimeters and LiF dosimeters.

Zusammenfassung

Arbeitsgruppen von verschiedenen Ländern nahmen an einem von der I.A.E.A. organisierten internationalen Vergleich von Unfalldosimetersystemen teil, bei welchem Kritikalitätsdosimeter am Health Physics Research Reactor in Oak Ridge mit einem gemischten Neutronen- und Gammastrahlungsblitz bestrahlt wurden. Der vorliegende Bericht gibt die abschließenden Meßergebnisse wieder, die mit dem im Kernforschungszentrum Karlsruhe benutzten Personendosimetersystem erhalten wurden.

Die Bestimmung der Dosis für die Freiluft- und Phantombestrahlungen erfolgte unter Zugrundelegung der Standardauswertemethode mit dem Routinepersonendosimeter, dem Phosphatglasdosimeter und den Schwellwertdetektoren. Bei dem Bestrahlungsexperiment wurden die dosimetrischen Eigenschaften eines Gürtels aus Polykarbonatfolie untersucht, mit welchem Neutronen oberhalb einer Schwelle von 1 MeV über neutroneninduzierte Rückstoßkerne und (n,α) Reaktionen in der Plastikfolie nachgewiesen werden. Der Einfluß von Spaltneutronen auf die Anzeige von Gammadosimetern wurde an verschiedenen Phosphatglasdosimetern und LiF Dosimetern untersucht.

Contents

Tables

Illustrations

1. Introduction

After the First International Comparison on Nuclear Accident Dosimetry Systems at the French Atom Energy Centre at Valduc in 197o (1), the I.A.E.A. organized a second intercomparison at O.R.N.L., Oak Ridge. The intercomparison experiments consisted of the exposure of dosimeters to pulsed radiation from the Health Physics Research Reactor, the simultaneous measurement of the detectors, a dose assessment for each exposure position and a comparison of the first results of the participants. During the meeting the participants discussed the concepts employed in criticality dosimetry as well as developments of better dosimeter systems and evaluation techniques. The I.A.E.A. also coordinates work on the collection and unification of leakage spectra from criticality assemblies.

The Karlsruhe Nuclear Research Centre took part in the international intercomparison at Oak Ridge with the routine personnel dosimeter and experimental dosimeters. The present experiments give us the opportunity to expose the Karlsruhe dosimeter to different energy spectra of neutrons and to compare our own results with the results from the other participants.

This report gives the final results of the Karlsruhe measurements. At the time of writing the results of the other participants are not yet available.

2. Irradiations

The Health Physics Research Reactor (HPRR) at O.R.N.L. is a bare unmoderated reactor, the core of which is composed of uranium enriched to 93 % alloyed with molybdenium (2). The reactor produces radiation bursts of about $8 \times 1o^{16}$ fissions per pulse. By using shieldings positioned on a circle of 2 m radius a modified fission spectrum was obtained.

The reactor was used in three different conditions:

- Pulse 1: reactor unshielded
- Pulse 2: reactor shielded by steel of 13 cm thickness
- Pulse 3: reactor shielded by lucite of 12 cm thickness

For each burst the dosimeters of the participants were irradiated in a free-air geometry (free air irradiation) and on the front side of two Bomab man-like phantoms (phantom irradiation) filled with o.9 % NaCl solution. The detectors were positioned on an arc at a distance of 3 metres from the reactor. Phantom A was placed facing the reactor, Phantom B was placed facing 9o° from Phantom A.

3. Dosimeters

The Karlsruhe Nuclear Research Center participated at the intercomparison study with the routine personnel dosimeter as well as with experimental detectors. Our routinely used standard dosimeter consists of a phosphate glass dosimeter in a spherical capsule and of a combination of activation detectors in an additional plastic badge (3) (see Fig. 1). The activation detectors are a sulphur pellet, a bare gold foil, a gold foil covered by indium foils inside a cadmium shielding, and as an experimental detector also bare and cadmium-covered arsenic glasses. The phosphate glass is also used as a neutron activation detector via the reactions $^{31}P(n,p)^{31}Si$ for fast neutrons $>$ 2.5 MeV and $^{31}P(n,\gamma)^{32}P$ for slow neutrons (4). The γ-Dosimeter is a Yokota glass of size 8 x 8 x 4.7 mm^3 inside a boron loaded plastic sphere and a perforated tin filter of 2 mm thickness.

The experimentally used threshold detector locket consists of neptunium, Makrofol E, thorium and uranium detectors which were electroplated in layers of about 4o $\mu g/cm^2$ on steel platelets of 1.2 cm diameter. The detectors are in contact with Makrofol N foils. Polycarbonate foils (Makrofol E) were also used as threshold detectors to measure neutrons above 1 MeV via recoils and (n,α) reactions. A plastic belt of Makrofol E was placed about the trunk of phantom A.

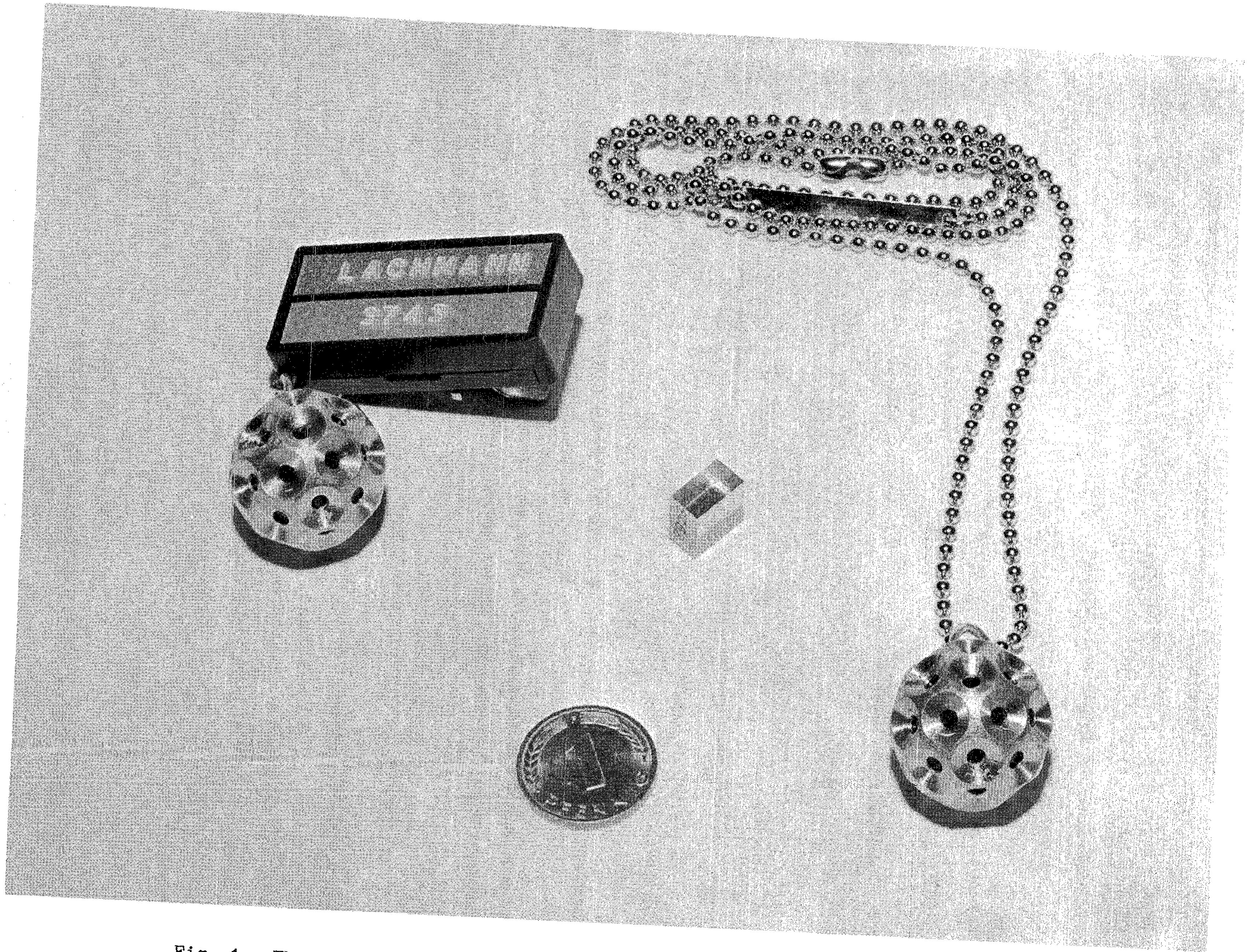


Fig. 1: The Personnel Dosimeter used at the Karlsruhe Nuclear Research Centre

All dosimeters were exposed on the chests of phantom A and phantom B. In addition, LiF ribbons of size 3 x 3 x 1 mm^3 (Harshaw TLD 100, TLD 600 and TLD 700) and a new phosphate glass with low sensitivity to thermal neutrons (Schott RPL-V glass) were exposed.

4. Evaluation Method

4.1 Personnel dosimeters

Two methods were used to assess the neutron dose:

- from the personnel criticality dosimeter a sulphur disc, a bare and a cadmium shielded gold foil were measured,
- from the phosphate glass the neutron-induced activation were measured within the first 15 hours (^{31}Si) and 24 hours (^{32}P) after the irradiation.

The neutron dose is calculated from the S and P activities on the basis of an unmoderated fission spectrum. The dose fractions of thermal and intermediate neutrons were determined from the Au - Au/Cd system or from ^{32}P assuming an intermediate $^1/E$ spectrum and a thermal Maxwellian spectrum. For pulse 2 the fast neutron dose was corrected using assumptions about the shape of the spectrum based on neptunium measurements or on the activity ratio $^{31}Si/^{76}As$ measured with the free air dosimeter.

4.2 Experimental dosimeters

The threshold detector system consists of the sulphur disc in the routine dosimeter, and of the additional fissionable isotopes uranium-238, thorium-232 and neptunium-237, without using a boron shield. Neutron-induced recoils and (n,α)-Reactions in a Makrofol E foil serve also as a threshold reaction. The approximate threshold energies of 2.5 MeV, 1.5 MeV, 1.2 MeV, 1 MeV and 0.75 MeV were taken into account for sulphur, uranium-237, thorium-232, Makrofol E and neptunium-237 respectively. The 40 $\mu g/cm^2$ thin oxyde layers of the fissionable materials are exposed in contact with Makrofol N foils. For the detection of fission fragment tracks the foils were etched for 4o min in a 35 % KOH solution at 6o°C, and for the detection of recoils and α-tracks for 4 hours in the same solution. The tracks were counted optically. The cross sections of the threshold detectors were estimated to rise abruptly at the threshold energy having a constant value above this threshold.

For the detection of intermediate neutrons a transparent As_2S_3 glass (disc of 1o mm ∅ , 1 mm) and a phosphate-arsenic glass (8 x 8 x 4.7 mm^3) were used bare and cadmium-covered. The reaction ^{75}As (n,γ) ^{76}As (T_H = 26 hours) has a cross section curve similiar to that of sodium, but without resonance peaks, and with a higher value by a factor of 1oo (5). In comparison to gold arsenic doesn't have the characteristics of a resonance detector. The activity ratio ^{31}Si/^{76}As of the arsenic glass measured with the free-air dosimeter gives an idea about the shape of the fission spectrum behind the reactor shielding.

Gamma-dose measurements were also performed with LiF-dosimeters. The corrections for the effect of neutron irradiation are nessessary for the sensitivity of ^{7}LiF to fast, intermediate and thermal neutrons. A new silver-activated phosphate glass (RPL-V glass, from Schott u. Gen.), with a low sensitivity to thermal neutrons, was also used for the gamma dose measurement at the free-air stations. Here no neutron-absorber or correction were applied for the effect of neutrons.

5. Results

5.1 Neutron measurements

For an intercomparison and interpretation of dose determination with that of other participants, the measured activities and fission rates of the neutron detectors have been converted to reaction rates normalised to $1o^{1o}$ atoms for each detector. The reaction rates for the neutron detectors in the personnel dosimeter exposed in free air are given in Tab. 1.

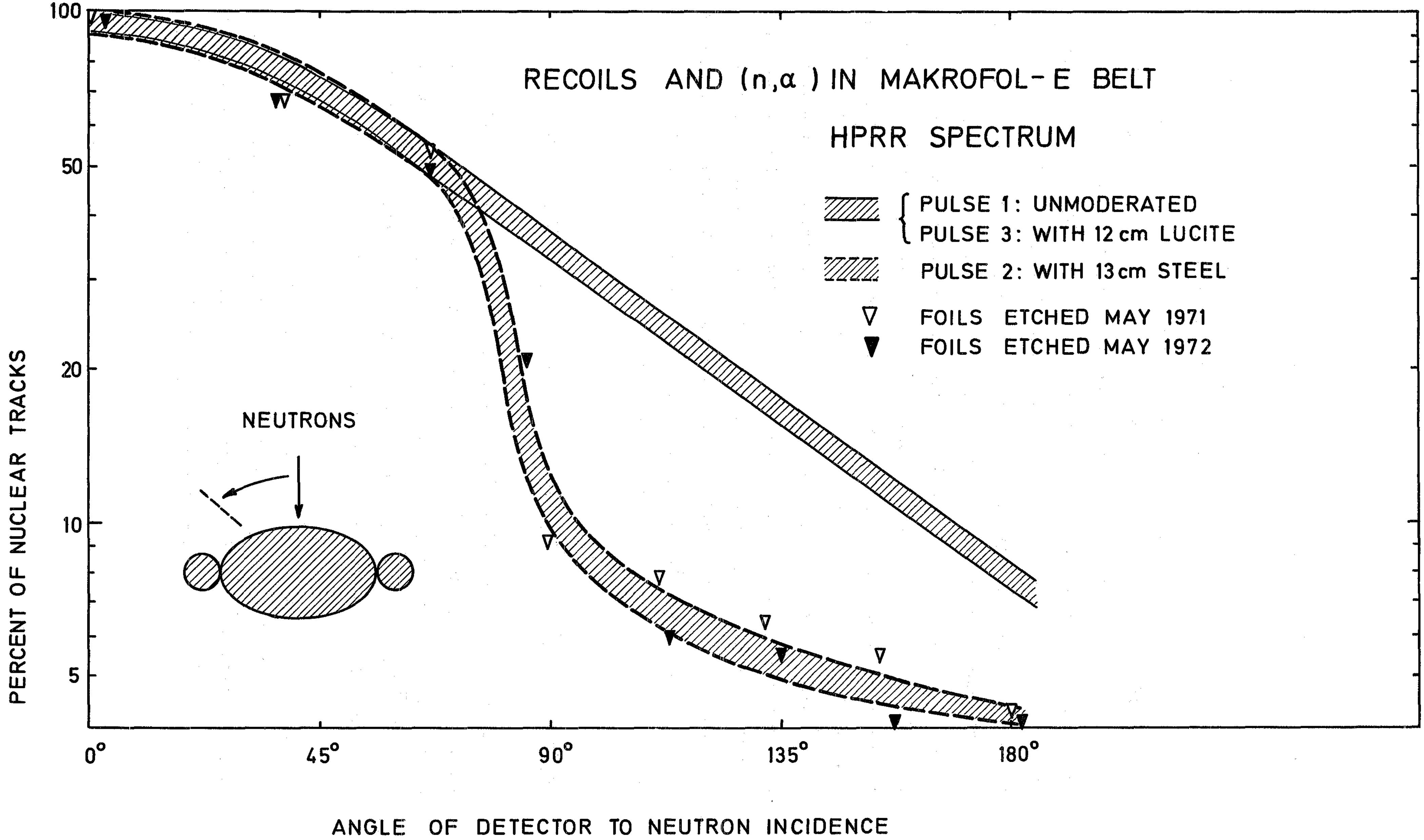
The results of fluence estimates are given in Tab. 2 and Tab. 3 for the activation detectors gold, arsenic, phosphate glass in the boron loaded capsule, and for the threshold detectors respectively.

The dose assessment for the personnel criticality dosimeter and the phosphate glass dosimeter are presented in Tab. 4.The results are given as Kerma (hectoerg · g^{-1}). The gold foil and sulphur activities were used in the standard way to give the thermal, intermediate and fast neutron dose. A similiar evaluation was used for the activation reactions in the phosphate glass dosimeter. The results for fast neutrons were corrected for pulse 2 based on neptunium and arsenic measurements.

A summary of neutron dose estimates found with the routine dosimeter and/or the experimental detectors based on different detector combinations are presented in Tab. 5. The results for phantom B, which was arranged sideways to the reactor, are not consistent for the different detectors because of a shielding effect of the phantom and other dosimeters respectively.

The final results used for the comparison with those of other participants are presented in Tab. 6 and Tab. 7. The dose estimates are given in kerma (hectoerg · g^{-1}) and absorbed dose in soft tissiue (rd). Free-air measurements were made with the personnel criticality dosimeter, the phosphate glass and the threshold detectors. The provisional results given during the Oak Ridge meeting are based on the phosphate glass dosimeter results. The gamma dose is corrected for the effect of slow neutrons.

The results for the personnel dosimeter exposed on the man-phantom are found with gold and sulphur detectors or with the phosphate glass activation. The absorbed doses at the front surface estimated with the standard interpretation were then converted to kerma using a constant conversion factor for the fission spectrum. The gamma dose given here is the total surface absorbed dose due to incident gamma rays and that produced by the $^{1}H(n,\gamma)^{2}D$ reaction in the phantom, which was measured with the phosphate glass dosimeter. The ^{24}Na activity of the phantoms were measured in a liquid scintillation counter. The sodium concentration of the phantom was 1.5 mg ^{23}Na/ml.


RECOILS AND (n,α) IN MAKROFOL-E BELT
HPRR SPECTRUM
PULSE 1: UNMODERATED
PULSE 3: WITH 12 cm LUCITE
PULSE 2: WITH 13 cm STEEL
FOILS ETCHED MAY 1971
FOILS ETCHED MAY 1972
NEUTRONS
PERCENT OF NUCLEAR TRACKS
100
50
20
10
5
0°
45°
90°
135°
180°
ANGLE OF DETECTOR TO NEUTRON INCIDENCE

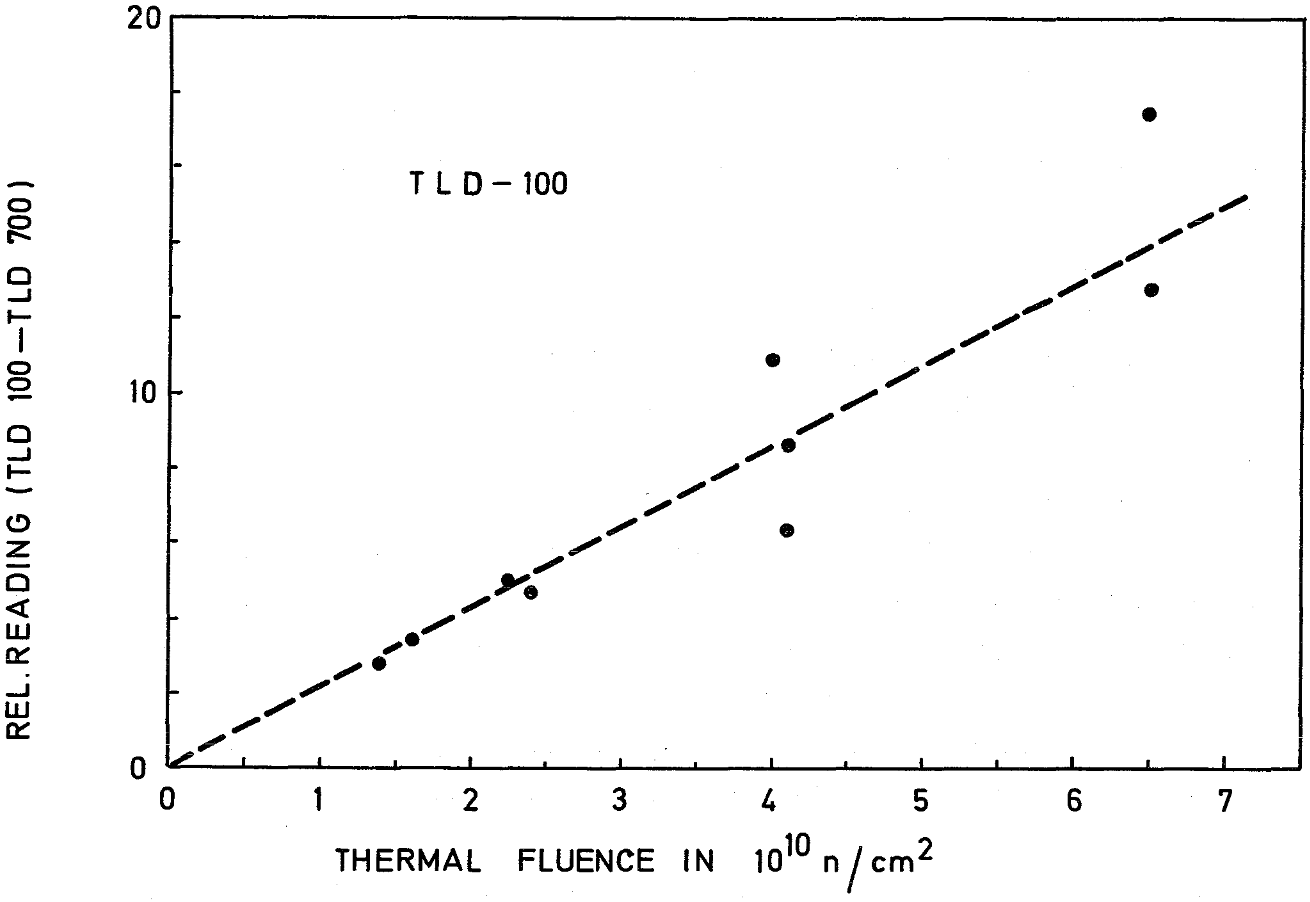
5.2 Phantom studies with a belt of polycarbonate

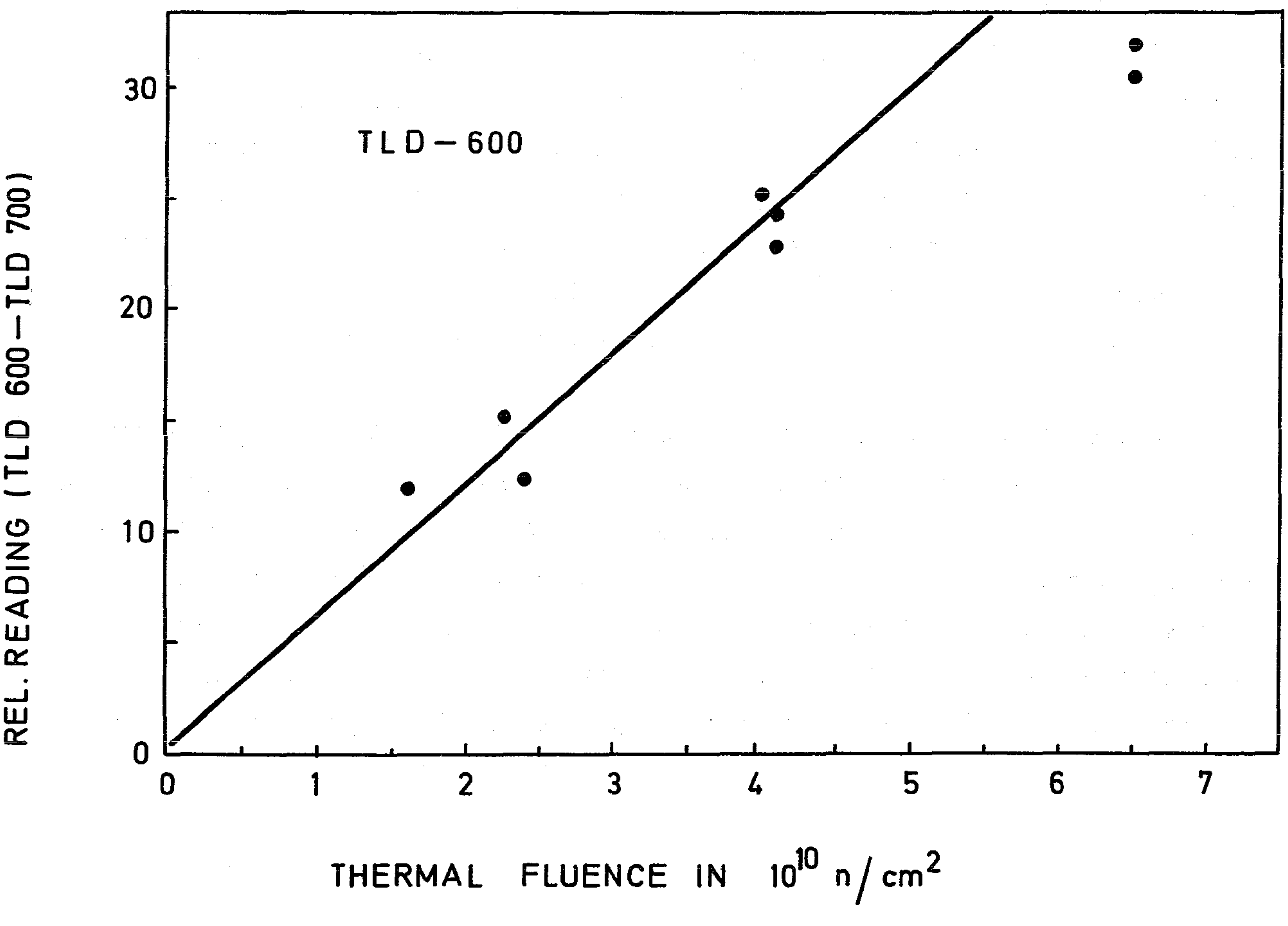
A plastic belt of Makrofol E is a simple detector to determine the direction of the neutron incidence after a criticality accident. For testing the practical application of such a belt a 5 cm wide Makrofol strip welded into a thinner foil was exposed on the man-phantom. After irradiation discs of 1 cm diam were punched out of the belt at uniform distances, etched and counted microscopically. The relative number of recoil and (n,α) tracks is presented in Fig. 2 as a function of the position of the detector with respect to the angle of radiation incidence for the phantom A facing the reactor. The decrease of track number up to 9o^{o} is mainly due to the directional dependence of the detector foil. The effect of body or arm shielding, and of the energy threshold (1 MeV) on the dose estimation is a factor of 3 higher for the neutron spectrum moderated by 13 cm steel than for the other spectra. No difference in the number of tracks were found for all neutron spectra, if the plastic belt was exposed on a bottle phantom of 18 cm diam (5). Also no fading effect was observed for the undeveloped etch pits in Makrofol E after one year. Phantom irradiations indicated that a remarkably strong effect is produced by the arms or other scattering materials near the body, in particular for radiation incident at 9o^{o} (5).

5.3 Gamma dose estimation with phosphate glass and LiF dosimeters

The gamma dose presented in Tab. 6 and Tab. 7 were measured with the phosphate glass (Toshiba FD-1 glass) in the boron-loaded sphere. The correction for the effect of slow neutrons is based on the neutron-induced ^{32}P activity in the phosphate glass. A dosimeter reading of 1o rd inside the boron loaded sphere corresponds to 1o^{1o} n/cm^{2} (1).

The effect of thermal and intermediate neutrons on the glass reading were studied with two different filters (the routine dosimeter constists of a boron-loaded spherical capsule with perforated 2 mm tin and a capsule of 1.2 mm tin) and two glasses (Toshiba FD-1 and Schott RPL-V glass).


TLD-100
REL. READING (TLD 100—TLD 700)
THERMAL FLUENCE IN 10^{10} n/cm^2
0
10
20
0 1 2 3 4 5 6 7


TLD-600
REL. READING (TLD 600—TLD 700)
THERMAL FLUENCE IN 10^{10} n/cm^2
0
10
20
30
0 1 2 3 4 5 6 7

The gamma dose readings of the dosimeters is given in Tab. 8 for the free-air station. The boron-loaded capsule reduces the neutron effect on the dosimeter reading up to a factor of 2. The RPL-V glass is practically insensitive to thermal neutrons (1.2 rd per $1o^{1o}$ n/cm^2) (6).

The sensitivity of LiF dosimeters to thermal neutrons was studied on Harshaw TLD 1oo, TLD 6oo and TLD 7oo dosimeters (ribbons of size 3 x 3 x 1 mm^3) which were exposed as a dosimeter triple. Knowing the sensitivity of TLD 7oo, the difference of dosimeter readings TLD 6oo - TLD 7oo and TLD 1oo - TLD 7oo is due to the effect of thermal neutrons. This value is independent of the gamma dose component and practically of the sensitivity to fast neutrons (Tab. 9). The results of these measurements are presented in Fig. 3 as a function of the neutron fluence for TLD 6oo and TLD 7oo. From this results average dosimeter readings of 6oo rd, 213 rd and 1.3 rd were found corresponding to a fluence of $1o^{1o}$ n/cm^2 for TLD 6oo, TLD 1oo, and TLD 7oo respectively.

In comparison to phosphate glasses TLD 7oo has a remarkable sensitivity to fast and intermediate neutrons. For the assessment of gamma dose, corrections of the measured dose are necessary due to the effect of thermal, intermediate and fast neutrons. A calibration exposure with unmoderated fission neutrons in the field of a ^{252}Cf-neutrons source led to a correction of the dosimeter of about 1.25 rd per $1o^{1o}$ n/cm^2 for fast and intermediate neutrons (7). The response of TLD 7oo to fast neutrons were found to be in good agreement with that from Tochilin whose value was 1 R per $1o^{1o}$ n/cm^2 from a criticality assembly (8). The TLD 7oo reading was corrected for the effect of neutrons in Tab. 1o.

The summary of the results from all gamma dose measurements are presented in Tab. 11. A comparison with other detectors shows that the TLD 7oo results agree sufficiently with the results of the other dosimeters. Nevertheless they are unsatisfactory due to the detailed correction in the different energy ranges and the remained discrepancy of the results. Further work is necessary to improve the corrections for the effect of intermediate neutrons, and/or the influence of other activation detectors, although no activation foils from our own criticality dosimeter were exposed nearby the LiF dosimeters.

Using phosphate glasses only one correction for slow neutrons was necessary, which can be done with high precision based on the activity measurements of ^{32}P of the same glass.

Acknowledgments

The author wishs to thank F.F. Haywood, and the staff of the HPRR for the kind hospitality and help during the intercomparison experiment.

References

(1) Piesch, E.: Report KFK 1462, 1971

(2) Auxier, J.A.: Health Physics 11, 89, 1965

(3) Maushart, R., Piesch, E.: Proc. Symp. on Lumines. Dosimetry, Stanford, 1965
Piesch, E.: Proc. 2nd Conf. Lumines. Dosimetry Gatlinburg, 1968

(4) Piesch, E.: Proc. of IAEA Symp. on Neutron Monitoring, 1966

(5) Piesch, E.: Proc. of IAEA Symposium on new Development in Phys., p. 399, 1971

(6) Doerfel, H.: Diplomarbeit, Universität Karlsruhe, 1972
Institut für Neutronenphysik und Reaktortechnik

(7) Piesch, E.: To be published

(8) Tochilin, E., Shumway, B.W.: in Radiation Dosimetry Vol. III, p. 278 Academic Press, 1969

(9) Majborn, B., et all: Proc IAEA Symposium Dosimetry Techniques 1972

Table 1: Reaction Rates for Personnel Dosimeter exposed in Free Air

REACTIONS PER 10^{10} ATOMS			
DETECTOR	PULSE 1	PULSE 2	PULSE 3
^{197}Au bare	$3{,}0 \cdot 10^{-2}$	$1.96 \cdot 10^{-2}$	$3.75 \cdot 10^{-2}$
^{197}Au in In, Cd	$2{,}07 \cdot 10^{-2}$	$1.41 \cdot 10^{-2}$	$1.45 \cdot 10^{-2}$
^{32}S bare	$6 \cdot 10^{-5}$	$1.06 \cdot 10^{-5}$	$0.96 \cdot 10^{-5}$
$^{31}P(n,p)^{31}Si$ +)	$3.22 \cdot 10^{-5}$	$0{,}455 \cdot 10^{-5}$	$0.43 \cdot 10^{-5}$
$^{31}P(n,\gamma)^{32}P$ +)	$3.48 \cdot 10^{-7}$	$2{,}45 \cdot 10^{-7}$	$3.6 \cdot 10^{-7}$
^{76}As bare	$1.15 \cdot 10^{-3}$	$0{,}68 \cdot 10^{-3}$	$1.04 \cdot 10^{-3}$
^{76}As in Cd	$7.3 \cdot 10^{-4}$	$4.35 \cdot 10^{-4}$	$2.65 \cdot 10^{-4}$
^{237}Np bare	$1.58 \cdot 10^{-3}$	$6.3 \cdot 10^{-4}$	$2.12 \cdot 10^{-4}$
^{232}Th bare	$6.3 \cdot 10^{-5}$	$1.9 \cdot 10^{-5}$	$1.2 \cdot 10^{-5}$

+) Phosphate glass in boron sphere (Routine γ-Dosimeter)

Table 2: Fluence Estimates for Activation Detectors

SLOW NEUTRON FLUENCE IN 10^{10} n/cm^2							
IRRADIATION		Au < 0.4 eV	Au +) > 0.4 eV	As < 0.4 eV	As ++) > 0.4 eV	As	Phosphate glass in B +++)
PULSE 1:	Free air	0.83	3.5	0.7	1.5	2.2	1.93
	Phantom A	6.5	11.8	4.6	4.4	9.0	6.7
	Phantom B	1.4	3.0	1.2	1.0	2.2	1.61
PULSE 2:	Free air	0.5	2.0	0.5	0.9	1.4	1.35
	Phantom A	4.1	7.1	5.0	0.5	5.5	3.75
	Phantom B	1.6	3.3	1.25	1.25	2.5	2.0
PULSE 3:	Free air	2.25	2.1	1.6	0.5	2.1	2.0
	Phantom A	4.0	3.1	2.5	0.9	3.6	3.1
	Phantom B	2.4	2.0	1.6	0.6	2.2	2.3

+) Au covered by In and Cd

++) Arsenic inside Cd

+++) Phosphate glass dosimeter (Routine γ-dosimeter) in the spherical capsule inside of a boron loaded plastic sphere

Table 3: Fluence Estimates for Threshold Detectors

	NEUTRONFLUENCE IN $1o^{1o}$ $^{n}/_{cm^2}$					
	^{237}Np > o.75 MeV	MAKROFOL > 1 MeV	^{232}Th > 1.2 MeV	^{238}U > 1.5 MeV	^{31}Si > 2.5 MeV	^{32}S > 2.5 MeV
PULSE 1						
Free air	1o	8.5	4.7	5.5	2.86	2.7
Phantom A	12.2	8.3	5.o		3.o4	2.9
Phantom B		o.5			o.51	o.5
PULSE 2 Free air	4.o	2.2	1.4	1.1	o.41	o.45
Phantom A	5.o	2.3	1.7		o.47	o.53
Phantom B		o.5			o.34	o.37
PULSE 3 Free air	1.34	1.26	o.9	o,7	o.39	o.42
Phantom A	1.45	1.3	1.3		o.46	o.46
Phantom B		o.9			o.41	o.37
PULSE 4 Free air		1o			2.96	3.o

Table 4: Dose Assessments for the Personnel Criticality Dosimeter and the Phosphate Glass Dosimeter

IRRADIATION		KERMA IN $h \cdot erg \cdot g^{-1}$							
		PERS. CRITICALITY DOSIMETER				PHOSPHATE GLASS DOSIMETER			
		Au < 0.4 eV	Au (in Cd, In)	S > 2.5 MeV	NEUTRON TOTAL	^{32}P > 0.4 eV	^{31}Si > 2.5 MeV	NEUTRON TOTAL	γ-Dose
PULSE 1:	Free air	0.38	8.9	335	343	4.9	358	363	52
	Phantom A	3.1	30	363	396	17	380	397	122
	Phantom B	0.7	7.2	65	72	4.1	64	68	47
PULSE 2:	Free air	0.23	5.1	140	145	3.4	127	130	11.5
	Phantom A	1.9	18.3	165	185	9.5	147	157	49
	Phantom B	0.75	8.4	115	123	5.1	107	112	28
PULSE 3:	Free air	1.1	5.4	53	59	5.1	48	53	37
	Phantom A	1.9	8.0	58	68	7.9	58	64	70
	Phantom B	1.1	5.2	46	52	5.9	51	57	57
PULSE 4:	Free air	0.45	9.3	372	383	5	370	375	58

Table 5: Summary of Dose Estimates

IRRADIATION			NEUTRON DOSE IN $h \cdot erg \cdot g^{-1}$					
PULSE	SHIELDING	LOCATION	Au, Np, U, S	Au, Np, S	Np	Makrofol recoils	Au, S	Phosphate glass
1	none	Free air	352	346	350	357	343	363
		Phantom A	407	448	438	348	396	397
		Phantom B				21	72	68
2	STEEL	Free air	132	136	140	92	61 (145)	55 (130)
		Phantom A	177	161	175	97	84 (185)	59 (157)
		Phantom B				21	51 (123)	47 (112)
3	LUCITE	Free air	50	53	47	53	59	53
		Phantom A	58	59	50	55	68	64
		Phantom B				38	52	57

Table 6: Dose Estimates for Personnel Dosimeter System exposed in Free Air

PULSE		FLUENCE IN 10^{10} n · cm^{-2}					KERMA h·erg·g^{-1}	NEUTRON DOSE +) rd	GAMMA DOSE rd
		n_{th}	> 0.4 eV	> 0.75 MeV	> 1.2 MeV	> 2.5 MeV			
1	Prov. Result	0.7					361		51
	Pers. Critic. Dos.	0.83	14.0	10.0	4.7	2.7	343	394	
	Phosphate glass					2.86	363	416	52
2	Prov. Result	0.42					131		11.5
	Pers. Critic. Dos.	0.5	6.0	4.0	1.4	0.45	145	167	
	Phosphate glass					0.41	130	150	11.5
3	Prov. Result	2.7					53		37
	Pers. Critic. Dos.	2.25	3.2	1.34	0.9	0.42	59	68	
	Phosphate glass					0.39	53	61	37
4	Prov. Result	0.96					381		56
	Pers. Critic. Dos.	1.0	15.0			3.0	383	440	
	Phosphate glass					2.96	375	431	58

+) Assumed dose at area dosimeter location

Table 7: Dose Estimates for Man Phantom exposed facing Reactor

Pulse		KERMA $h \cdot erg \cdot g^{-1}$	NEUTRON DOSE (rd) RECOILS + P	NEUTRON DOSE (rd) $H(n,\gamma)$	GAMMA+) DOSE (rd)	µCi ^{24}Na / mg ^{23}Na Phantom A	µCi ^{24}Na / mg ^{23}Na Phantom B
1	Prov. result		387		122	$1o \cdot 1o^{-4}$	$6,8 \cdot 1o^{-4}$
	Pers. Critic. Dos.	344	396				
	glass dosimeter	345	397		122		
2	Prov. result		157		49	$4,5 \cdot 1o^{-4}$	$3,2 \cdot 1o^{-4}$
	Pers. Critic. Dos.	161	185				
	glass dosimeter	137	157		49		
3	Prov. result		64		7o	--	--
	Pers. Critic. Dos.	59	68				
	glass dosimeter	56	64		7o		

+) Dose measurement at front surface

Table 8: γ-Dosimeter Reading of Phosphate Glasses in the Spherical Capsule and in a Tin Capsule for Free Air-Station

PULSE	Phosphate Glass	Dosimeter Reading (rd)		$\frac{D\ (Sn)}{D\ (boron)}$ +)
		D (boron)	D (Sn)	
1	FD-1	70	84	1.2
	RPL-V	47.5	47	0.99
2	FD-1	24	30	1.25
	RPL-V	15	15	1.0
3	FD-1	56	114	2.04
	RPL-V	39	41.5	1.06

+) Phosphate glass in 1.2 mm tin capsule and in the routine dosimeter capsule inside of a boron plastic sphere

Table 9: Dosimeter Reading of LiF-Dosimeter

PULSE	LOCATION	Dosimeter Reading (rd)		
		TLD 700	TLD 600 - TLD 700	TLD 100 - TLD 700
1	Free air	--	--	--
	Phantom A	180	3070	1270
	Phantom B	62	1020	273
2	Free air	--	--	--
	Phantom A	76	2424	864
	Phantom B	37	1203	338
3	Free air	58	1492	512
	Phantom A	97	2503	1093
	Phantom B	61	1220	469

Table 1o: Gamma dose Estimates for TLD-7oo

		^{7}LiF READING (rd)				
PULSE	LOCATION	MEASURED VALUE	CORRECTION FOR n_{th}	n_m	n_f	CORRECTED VALUE
1	Free air	78	1,1	1o,5	12,5	54
	Phantom A	171	8,5	35	15,2	112
	Phantom B	59	1,8	9	2,5	46
2	Free air	24	0,7	6	5,o	12
	Phantom A	72	5,3	21	6,3	39
	Phantom B	35	2,1	14	4,8	15
3	Free air	55	2,9	6	1,7	44
	Phantom A	92	5,2	9	1,8	76
	Phantom B	58	3,1	6	1,6	47

Table 11: γ-Dose Estimates for the LiF-Dosimeter and the Phosphate Glass Dosimeter in the spherical capsule

		Dosimeter Rading (rd)				
PULSE	LOCATION	TLD-7oo measured	TLD-7oo corrected +)	Personnel Dosimeter measured	Personnel Dosimeter corrected ++)	Glass RPL-V +++)
1	Free air	78	54	7o	52	48
	Phantom A	171	112	184	122	--
	Phantom B	59	46	62	47	--
2	Free air	24	12	24	12	15
	Phantom A	72	39	85	49	--
	Phantom B	35	15	46	28	--
3	Free air	55	44	56	37	39
	Phantom A	92	76	1oo	7o	--
	Phantom B	58	47	79	57	--

+) corrected for thermal and fast neutrons, see Table

++) Routine personnel dosimeter: Toshiba FD-1 glass inside of a boron plastic sphere

+++) the same dosimeter capsule with Schott RPL-V glass, which has a low sensitivity to thermal neutrons.