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HEAT-UP EFFECTS OF GAMMA SHOWERS ON NINE SAMPLE MATERIALS IN TRIUMF NEUTRON SOURCE GEOMETRY

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SUMMARY

The Monte-Carlo programme EGS[1] was used to follow the propagation of electron-gamma showers through the geometry of the TRIUMF neutron source, and to estimate the resulting energy deposition in nine sample materials.

INTRODUCTION

Following the Monte-Carlo study[2] of the heat-up of samples of 9 materials by the nuclear cascades of protons at 520 MeV in the approximate geometry of the TRIUMF neutron source, the Monte-Carlo programme EGS was used to investigate the additional, simultaneous heat-up of the same 9 samples by the effect of:

i) the gamma showers from neutral pion decay, and

ii) the prompt nuclear gamma showers

which are produced in the lead target by the nuclear cascades. The 9 sample materials are Be, C, Al, Fe, Cu, W, Pb, Bi, and heavy water. The effects of proton beam lateral displacement and beam spot size were also briefly examined.

In order to allow the flexible handling of the somewhat complicated geometry of the target arrangement (see Fig. 1), the geometry package of HET was linked to the EGS code and used in this study.

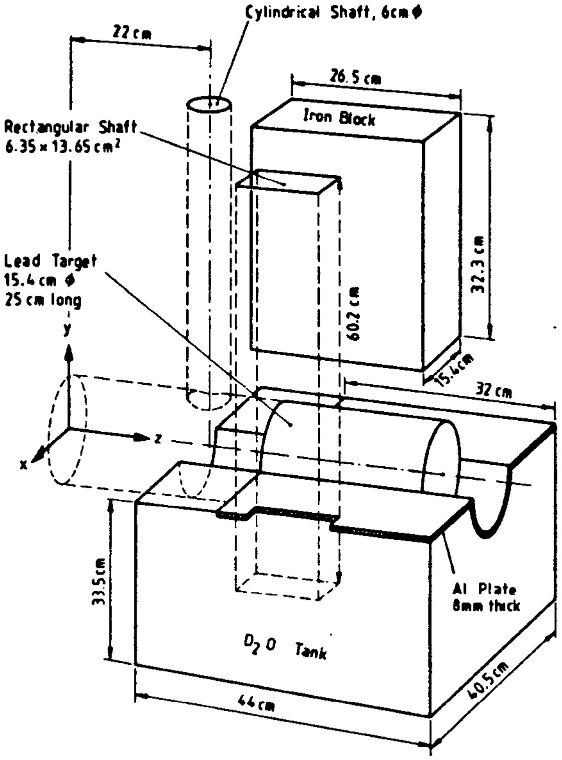

Fig. 1 Simplified geometry of the central region of the TRIUMF neutron source, as used in the Monte-Carlo study.

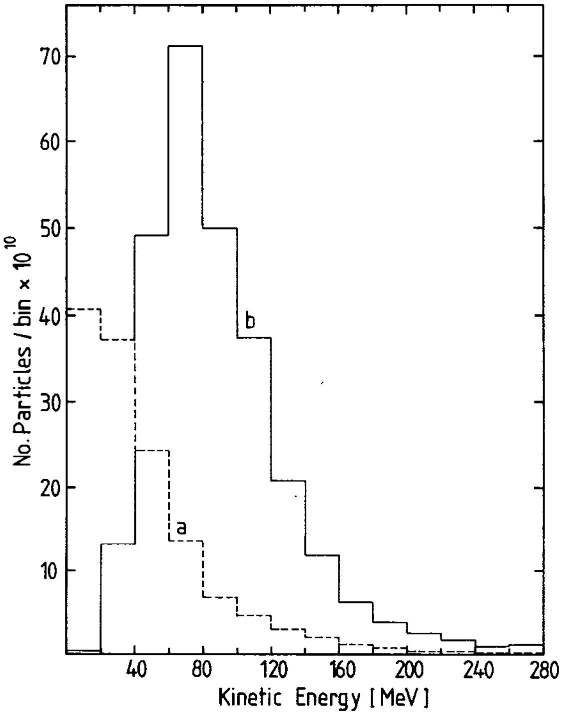

Fig. 2 Kinetic energy spectrum of a) the neutral pions generated in the nuclear cascades, and b) the resulting decay gammas.
Histogrammes are normalised to 10 µAs of incoming proton beam.

PARAMETERS OF THE SOURCE GAMMAS

For the gammas from neutral pion decay, the pion energy spectrum and the normalisation factor of one pion per 46 incident protons were taken from the 520 MeV nuclear cascade study. The pion spectrum and the resulting spectrum of the original gammas, obtained under the assumption that the pions are produced isotropically in the lab, are shown in Fig. 2. The mean gamma energy is 89.7 MeV, the mean z-value (z is the direction of the proton beam) lies 4.6 cm deep in the lead target. The distribution of shower origins in the plane perpendicular to the proton beam was assumed identical to the beam shape, i.e. gaussian, with 95 % of the probability within a spot of 3 cm diameter; tails outside a radius of 5 cm were cut off.

For the prompt nuclear gammas, the same x, y, and z distributions were taken as for the gammas from neutral pion decay. Following F. Atchison, W.E. Fischer and B. Sigg[3], the normalisation factor was taken to be 1.2 gammas per incident proton, and the source spectrum was assumed to be in good approximation rectangular between 1 and 9 MeV.

METHOD

In order to save computing time, the propagation of all shower particles was suspended when the particles escape the surface of the lead target. All escaping particles were then rotated by that multiple of 60 degrees which was necessary to bring them into the 60 degree sector of the target which faces the sample; the propagation of the shower was then resumed. The shower particles were also rotated by 60 degrees more and 60 degrees less than necessary, in order to judge the contribution of the neighbouring sectors to the flux incident on the sample. The spectrum of photons incident on the sample was obtained, and EGS was used again to estimate the energy deposits in the sample.

RESULTS

Table I presents compared values of particle energies and fluxes for the neutral pion decay and the prompt nuclear gamma showers (photons below 1 MeV were not included in these statistics, as they contribute considerable numbers of particles, but less than 10 % of the energy). The energy spectra of the gammas incident on the sample are shown in Fig. 3. Table II gives the sample heat-ups for the 9 materials. All results are normalised to 10 µAs of incoming protons.

CHECK OF THE RESULTS

In a very rough hand calculation, the gamma source was assumed to be a mono-energetic, isotropically emitting point, located at the centre of mass of shower origins. The energy incident on the sample was then given by the source strength, times the solid angle factor, times (for each intervening medium) the product of the thin-beam attenuation for that thickness of medium and the energy fluence buildup factor for the mean photon energy at entrance to that medium (the mean photon energy was taken from the EGS intermediate results). The heat deposited in the samples of Al, Fe, Pb and heavy water, for which buildup factors could be found in the literature, were estimated by calculating in a similar way the energy transmitted through the sample and assuming the complements of energy to have been deposited.

In these calculations, and for photon energies below 10 MeV, the buildup factors were taken

	π^0 decay showers	Prompt nuclear showers
No. of incoming protons	$6.24 \cdot 10^{13}$	$6.24 \cdot 10^{13}$
No. of electron-gamma cascades	$2.71 \cdot 10^{12}$	$7.49 \cdot 10^{13}$
Total energy of initial gammas (MeV)	$2.43 \cdot 10^{14}$	$3.75 \cdot 10^{14}$
Mean energy of initial gammas (MeV)	89.7	5.0
No. of particles above 1 MeV escaping target from side	$0.45 \cdot 10^{12}$	$2.15 \cdot 10^{12}$
Total kin. energy of the above (MeV)	$3.70 \cdot 10^{12}$	$7.50 \cdot 10^{12}$
Mean kin. energy of the above (MeV)	8.1	3.5
Composition of the above	96 % gammas	99 % gammas
No. of particles above 1 MeV incident on the sample	$1.10 \cdot 10^{10}$	$1.90 \cdot 10^{10}$
Total kin. energy of the above (MeV)	$4.20 \cdot 10^{10}$	$6.70 \cdot 10^{10}$
Mean kin. energy of the above (MeV)	3.8	3.5
Composition of the above	98 % gammas	99 % gammas

Table I Some parameters characterising the flux, energy content, and composition of the electron-gamma showers at various stages of their propagation: at source, at the side exit point from the cylindrical lead target, and at the point of incidence on the sample.

Sample	π^0 decay showers		Prompt nuclear γ showers		Nuclear cascades	
	E_{dep} [MeV/sec cm^3]	$(dT/dt)_0$ [^{0}C/sec]	E_{dep} [MeV/sec cm^3]	$(dT/dt)_0$ [^{0}C/sec]	E_{dep} [MeV/sec cm^3]	$(dT/dt)_0$ [^{0}C/sec]
D_2O	$0.38 \cdot 10^8$	$0.13 \cdot 10^{-5}$	$0.42 \cdot 10^8$	$0.15 \cdot 10^{-5}$	$8.62 \cdot 10^9$	$3.0 \cdot 10^{-4}$
Be	$0.46 \cdot 10^8$	$0.21 \cdot 10^{-5}$	$0.80 \cdot 10^8$	$0.38 \cdot 10^{-5}$	$7.47 \cdot 10^9$	$3.5 \cdot 10^{-4}$
C	$0.76 \cdot 10^8$	$1.10 \cdot 10^{-5}$	$1.24 \cdot 10^8$	$1.81 \cdot 10^{-5}$	$5.28 \cdot 10^9$	$7.6 \cdot 10^{-4}$
Al	$0.82 \cdot 10^8$	$0.54 \cdot 10^{-5}$	$1.50 \cdot 10^8$	$0.99 \cdot 10^{-5}$	$3.68 \cdot 10^9$	$2.4 \cdot 10^{-4}$
Fe	$2.92 \cdot 10^8$	$1.32 \cdot 10^{-5}$	$4.12 \cdot 10^8$	$1.86 \cdot 10^{-5}$	$6.79 \cdot 10^9$	$3.1 \cdot 10^{-4}$
Cu	$3.50 \cdot 10^8$	$1.63 \cdot 10^{-5}$	$5.52 \cdot 10^8$	$2.57 \cdot 10^{-5}$	$6.76 \cdot 10^9$	$3.8 \cdot 10^{-4}$
W	$6.00 \cdot 10^8$	$3.72 \cdot 10^{-5}$	$9.62 \cdot 10^8$	$5.97 \cdot 10^{-5}$	$6.06 \cdot 10^9$	$3.8 \cdot 10^{-4}$
Pb	$4.38 \cdot 10^8$	$4.79 \cdot 10^{-5}$	$7.42 \cdot 10^8$	$8.11 \cdot 10^{-5}$	$2.98 \cdot 10^9$	$3.3 \cdot 10^{-4}$
Bi	$3.70 \cdot 10^8$	$4.81 \cdot 10^{-5}$	$6.58 \cdot 10^8$	$8.57 \cdot 10^{-5}$	$2.66 \cdot 10^9$	$3.5 \cdot 10^{-4}$

Table II Energy deposition E_{dep} per cm^3 of sample and per sec, and initial rate of sample heat-up $(dT/dt)_0$ for nine sample materials and for pion decay and prompt nuclear γ showers. Pro memoria, the corresponding quantities for nuclear cascades (results of ref. 2), are also shown. All figures are normalised to a 10 µA incoming proton beam.

from the Engineering Compendium on Radiation Shielding[4]. For the propagation of the neutral pion decay showers through the lead target of 7.7 cm radius, a kind of "buildup factor" was defined by estimating the unscattered escaping energy (thin beam approximation) and comparing it with the total energy transmitted through a 7.7 cm thick lead slab, as given by Messel and Crawford[5]. A value of 199 was obtained.

Comparison of these hand calculations with the EGS results shows good agreement (discrepancies between 2 % and 15 %) whenever the photon energies are below 10 MeV, i.e. everywhere except for the propagation of the pion decay showers through the lead target. In this last situation the hand calculation leads to a value 42 % larger than the value given by EGS.

EFFECTS OF BEAM VARIATION

In order to ascertain the effects of lateral beam displacement and beam spot size on the sample heat-up, EGS was used to estimate the amounts of energy incident on the sample when the distribution of shower origins was displaced laterally by 1.5, 3.0 and 4.5 cm towards the sample, and when the distributions of shower origins in the x-y plane were assumed uniform within concentric rings with limiting radii of 1.1, 2.2, 3.3, 4.4, 5.5, 6.6, and 7.7 cm. Because of the limited computing time available, only the showers from neutral pion decay were thus investigated, and the statistics used in these studies were considerably reduced, so that the number of photons above 1 MeV incident on the sample was as low as 8 (for shower origin

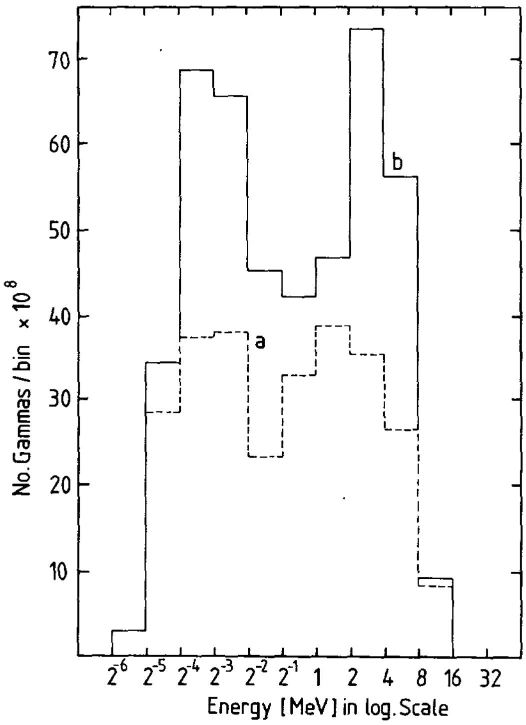

Fig. 3 Energy spectra of gammas incident on the samples under study for a) showers originating in neutral pion decay, and b) showers from prompt nuclear gammas. Histogrammes are normalised to 10 µAs of incoming proton beam.

Description of incoming proton beam	Energy incident on sample Absolute in MeV (for 10 μamp sec beam)	 As multiple of case with "standard" beam
a) "Standard" beam	$4.2 \cdot 10^{10}$	1.0
b) Beam 1.5 cm off-center	$7.0 \cdot 10^{10}$	1.5
Beam 3.0 cm off-center	$12.0 \cdot 10^{10}$	2.7
Beam 4.5 cm off-center	$76.0 \cdot 10^{10}$	16.4
c) Ring 1 $0 \leq r < 1.1$ cm	$2.4 \cdot 10^{10}$	0.5
Ring 2 $1.1 \leq r < 2.2$ cm	$2.9 \cdot 10^{10}$	0.6
Ring 3 $2.2 \leq r < 3.3$ cm	$3.4 \cdot 10^{10}$	0.7
Ring 4 $3.3 \leq r < 4.4$ cm	$14.1 \cdot 10^{10}$	3.0
Ring 5 $4.4 \leq r < 5.5$ cm	$22.2 \cdot 10^{10}$	4.8
Ring 6 $5.5 \leq r < 6.6$ cm	$21.1 \cdot 10^{10}$	4.5
Ring 7 $6.6 \leq r < 7.7$ cm	$122.0 \cdot 10^{10}$	26.0

Table III Energies incident on the sample in the form of γ showers for a) the original, "standard" beam, b) the same beam laterally displaced towards the sample by various amounts, and c) seven centered but ring-shaped beams. The results are given in absolute values (normalised to 10 μAs of protons on the lead target), and as a multiple of the energy incident on the sample in the "standard" case.

distributions concentrated near the axis of the target). The statistical errors are correspondingly large.

The results, given in Table III, show that beam mis-alignment and blow-up could account for gamma heat-up effects up to an order of magnitude greater than the values obtained with the "standard" beam.

ACKNOWLEGEMENTS

F. Atchison pointed out the possibility of linking the HET geometry package to the EGS code and showed me how it is done. His help in tracing and eliminating the ensuing bugs no doubt saved me a very great amount of time.

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