THE BIOLOGICAL EFFECT OF VERY HIGH-ENERGY HADRONS

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SUMMARY

Biological irradiations have been made in a 250 GeV/c positive hadron beam from the CERN Super Proton Synchrotron (SPS) as an exploratory investigation into the biological effectiveness of very high energy radiation. On account of the low ionization density along the track of fast charged particles the RBE may be expected to be near unity, however, it was found to depend on dose and on the biological system used¹⁾. Therefore the experiment was planned to cover a range of RBE values from 1 to 3. The verification of these RBE's has obvious implications for radiation protection. The biological tests reported here (the 10-day growth reduction in *Vicia faba*) indicate an RBE near to one independent of the contribution of secondaries to the dose. However, some anomalies in the radiation response of the irradiated beans were noted.

The 10-day growth inhibition of *Vicia faba* bean roots was considered a suitable test system as the preparation of the biological material can be made at short notice when accelerator time becomes available, and it has been extensively used in studies with other high-energy particle beams^{2,3)}. The bean-root system is also particularly well adapted to accelerator beam radiobiology when the beans are cooled to 4°C⁴⁾, which makes them

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relatively insensitive to beam intensity variations and the occasional beam interruption. Another constraint on the choice of the biological system was the limited beam area available.

The beam was of secondary hadrons produced from primary 400 GeV/c protons incident on a target. The beam line selected 250 GeV/c hadrons which were mainly protons with about 10% positive pions. The beam was collimated, which gave it a rectangular profile of about 30 x 40 cm over which the intensity did not vary by more than 10% from the mean. The radiation was pulsed, each pulse being about 1.4 sec long and at a frequency of one per 9.6 sec. The intensity of the beam was monitored with a transmission ionization chamber which was also used as a reference for the biological irradiations. A 0.1 cm³ tissue-equivalent ionization chamber was used to measure the dose rate in the beam at different depths in a water absorber. The dose rate as a function of water depth for a nominal beam of 5×10^7 particles per pulse is shown in Fig. 1. At very small absorber depths the dose rate was determined by means of a thin-walled parallel-plate chamber to which sheets of polythene were added. No marked rapid initial dose build-up was detected even in the first 100 mg/cm². The water depth at the dose rates for the measurements are also given in the figure.

Groups of 15 to 20 beans were irradiated with doses from about 0.40 to 2.60 Gy in tanks in which the water was circulating at 4°C. The beans were then transferred to growing tanks in which fresh, filtered water at 19°C was circulating. The root length was measured daily for the subsequent 12 days. The percentage growth determined after 10 days at the four different irradiation positions are plotted in Fig. 2 as a function of dose. This relative growth has been compared to that occurring after irradiation with Co-60 gamma rays. The lines drawn through the data are those obtained with gamma rays at 0.8 Gy/h and 4.7 Gy/h. The RBE's determined at 80%, 50%, and 30% are given in Table 1. Dose-rate effects have been taken into account. As can be seen all RBE's are of the order of unity independent of the degree of effect and the depth at which the beans were irradiated in spite of differences on the contribution of secondary particles to the dose.

A strong dependence of RBE values on dose and biological system used have been reported after a 70 GeV/c hadron irradiation leading to RBE values

up to 34 at small doses¹⁾. For the lethality and the growth of *Vicia faba* seeds RBE values of 1.9 and 1.6, respectively, were determined, using as reference radiation gamma rays from ¹³⁷Cs⁵⁾.

Although in our experiment the 10-day growth reduction showed a similarity to that observed with gamma rays, anomalies were detected in the degree of darkening (Fig. 3) and in the death rate of the beans. These data are summarized in Table 2, where death rate and growth rate are compared for similar doses of gamma rays and high-energy hadrons. From this table it can be seen that not only is the bean death rate higher with high-energy hadrons but it also seems to vary with the depth at which they were irradiated.

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FIGURE CAPTIONS

- Fig. 1 : Dose rate in the beam as a function of depth in water for a beam of 5×10^7 protons per pulse. The arrows indicate the irradiation positions.
- Fig. 2 : The experimental measurements of 10 day growth plotted as a function of hadron dose for different depths in water. The curves show results obtained from a 60-Co gamma ray experiment at two different dose rates.
- Fig. 3 : Various degrees of root darkening after different hadron doses.
- Table 1 : RBE's calculated for various levels of percentage of 10 days' growth.
- Table 2 : Percentage of dead beans observed after a comparable radiation dose. The statistical uncertainties have been calculated using Laplace statistics.

Table I

250 GeV hadrons	R.B.E.		
	80% growth	50% growth	30% growth
250 mg/cm ² 0.90 Gy/h	1.08 ± 0.09	1.02 ± 0.03	1.00 ± 0.05
8250 mg/cm ² 1.70 Gy/h	1.14 ± 0.13	1.09 ± 0.04	1.07 ± 0.04
16250 mg/cm ² 2.40 Gy/h	1.18 ± 0.13	1.05 ± 0.04	1.01 ± 0.05
32250 mg/cm ² 3.90 Gy/h	0.96 ± 0.07	1.00 ± 0.02	1.01 ± 0.03

Table II

Water depth mg/cm ²		Dose rate Gy/h	Dose Gy	Dead beans percentage	10 days growth Mean ± SE mm
250 GeV hadrons					
	Controls	-	-	1.8 ± 1.3	254.6 ± 4.1
	250	0.90	2.35	38 ± 8.3	103.0 ± 7.4
	8250	1.40	2.48	79 ± 6.5	72.3 ± 3.9
	16250	2.40	2.50	64 ± 8.0	81.4 ± 5.0
	32250	3.90	2.42	47 ± 8.8	83.0 ± 6.3
⁶⁰ Co γ rays					
	Controls	-	-	0	251.2 ± 3.7
	3000	0.8	2.50	19 ± 7.7	85.1 ± 3.3
	3000	4.7	2.52	27 ± 7.7	75.2 ± 3.2

fig. 1