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RADIOPROTECTION AROUND PLASMA-FOCUS MACHINES.

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Radioprotection Around Plasma-Focus Machines

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Introduction

RECENT developments in Plasma-Focus machines have been dealt with in a number of publications that have pointed out the importance of these machines as high power neutron pulsed generators and in the study of thermonuclear reactors (BERNSTEIN *et al.*, 1968; FILIPPOV and FILIPPOVA, 1969; LUZZI and SAMUELLI, 1970; MAISONNIER *et al.*, 1970; MATHER, 1965).

On the contrary, poor attention, at least: in the literature has been paid to radioprotection problems connected with the operation of these machines, which require some consideration. Therefore, we think it useful to discuss in the present paper the main aspects of radioprotection around Plasma-Focus machines, in consideration also of the fact that more and more powerful machines are foreseen to be operated in the future. References to the experiences we have had with the machines installed in the Frascati Center will be useful to us in the discussion of the various problems.

We think it convenient to remind you of some principal characteristics of the Plasma-Focus machines, even if a detailed technical description of their working, which may be found in the specialized bibliography (SAMUELLI, 1973), remains outside our intentions.

A Plasma-Focus machine consists of an experimental chamber where two metal electrodes, conveniently shaped and separated from each other by an insulator, are placed, and a low inductance capacitor system connected to the chamber by means of spark gaps. At present two different geometries are used for electrodes, according to which the machines are called the Mather type or the Filippov type. Anyway, the two different types of machines work alike.

After the vacuum is made and the capacitor system is stored, a uniform pressure gas (deuterium or a deuterium and xenon mixture) is introduced into the chamber. Then a capacitor system voltage of the order of some 10 kV is discharged between the electrodes. Thus a hot and dense plasma is generated for 100 nsec, which has about 1 cm^3 volume, 10^{18} – 10^{19} part/cm^3 density and temperature of the order of 10^7–10^8 °K.

Discharges have been studied by means of various experimental techniques as a number of parameters were varied. From our point of view it will be sufficient to report that where potential differences occur above a given threshold (i.e. 15 kV when pure deuterium is used at a pressure of the order of 1 mmHg) there is intense emission of neutrons, accompanied by X-rays, in durations of about 100 nsec. The number of neutrons emitted may be of the order of 10^{10}–10^{11} per pulse with 50 kJ capacitor systems and depends on various experimental parameters (i.e. nature and geometry of electrodes, etc.). The presence of impurities may also exert remarkable influence on the number.

Emitted radiation has been the subject of many studies and various models have been proposed to interpret its origin (LUZZI and SAMUELLI, 1970), even if definitive formulation has not been achieved so far. Anyway, it is certain that neutrons are generated through reactions of the D–D type. Figure 1 shows the spectrum measured around the Filippov machine in Frascati. In view of radioprotection aims at least, the angular distribution may be considered as isotropic. In fact, an asymmetry of about 30% has been noticed, for the Frascati machines at least, between the number of neutrons emitted upwards and the downwards one (LUZZI and SAMUELLI, 1970).

The electromagnetic radiation present around the machines may be divided into two components, one formed by X-rays of energy above some 10 keV and the other by γ-rays of energy above some 100 keV. The former are emitted directly during discharge and are due to bremsstrahlung of electrons and deuterons inside the chamber. The latter might be interpreted, as originating in the (n, n′γ) inelastic scattering processes that neutrons undergo in the materials constituting the experimental chamber. However its contribution to the total dose around the machines is unimportant. The X-rays of very low energy stopped by the walls of the chamber will be neglected in this note.

Radioprotection Problems

At present two Plasma-Focus machines are operating in the Laboratori Gas Ionizzati at the Frascati Center, one of the 120 kJ–40 kV Filippov type and the other of the 40 kJ–40 kV Mather type. They can operate up to a repetition rate of 1 pulse/min but work at lower frequencies really.

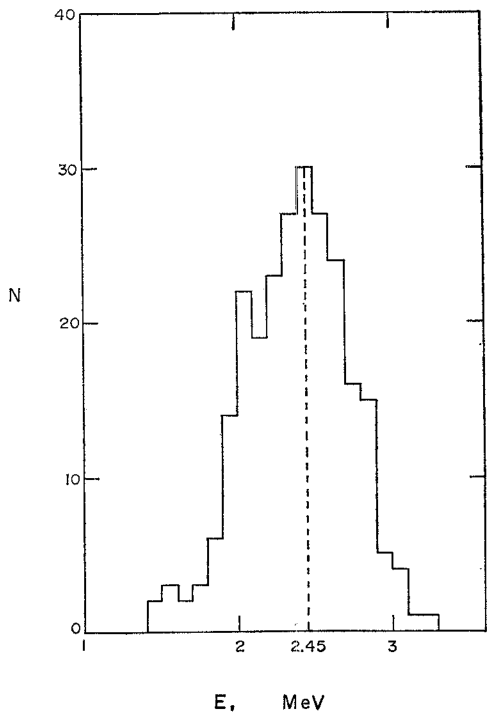

FIG. 1. Energy spectrum of the neutrons by the Plasma-Focus (MAISONNIER *et al.*, 1971).

Of course, the first radioprotection precaution for the machines of such a kind consists in an efficient shielding. In our case shielding has been obtained by means of concrete blocks. Shield thickness has been properly fixed so that operators may stay in the proximity of the machines during operation and maximum permissible doses in outside areas, which are nearby in our case, are not exceeded. As regards dosimetric instrumentation, some problems arise concerning the neutron component measurement, on account of the characteristics of the pulse of the machine (10^{10}–10^{11} neutrons emitted together with X-rays in about 100 nsec).

The instrumentation needs to meet well defined requisites: the possibility of discriminating the neutron component from X-rays; high counting-rate capacity in measurements where high fluxes are present; and high efficiency in measurements where, on the contrary, the fluxes are modest.

As no instrumentation can be found with all the above quoted requisites we have opted for a mixed solution, namely we have used different detectors according to the distance of the source and therefore of the neutron fluence. Detectors have been chosen among those displaying poor sensitivity to X-rays.

A Neutron Rem Counter has been chosen for measurements where fluxes are modest. It has good sensitivity and low background and responds in dosimetric units directly; this is important in our case due to the contribution from neutrons scattered by the walls. Measurements must be made over a long period of time (i.e. 24 hr), and one has to be careful to keep the counter operating only during neutrons bursts so that background remains low and to avoid possible failures of a.c. mains. On account of the high dead time (about $5 \cdot 10^{-7}$ sec) and because of the neutron thermalization time in the moderator (about 60 μsec), it is not possible to obtain more than 100 counts/pulse with these counters. Therefore, they may be used only where there are dose equivalents per pulse smaller than about 10^{-2} mrem/pulse. In our case, all shielded areas meet these conditions.

On the other hand, the above described counter cannot be used inside shieldings. Of course, people cannot stay in these areas when machines are operating but it is of interest to know these fluxes or doses. The aim of these measurements was correlation with doses in the regions where people are admitted as well as of estimating possible accidental overexposures, even if they are improbable because of the precautions taken to avoid them.

An activation silver counter has been set up with a moderator for measurements in these areas. It has smaller sensitivity but offers a high counting capacity (of the order of 10^4–10^5 counts per pulse in our conditions). For simple data interpretation, a period of time sufficient to let silver decay (several minutes) is required between pulses. A response in dosimetric units may be obtained if the detector is introduced into a moderator similar to that of a Neutron Rem Counter.

With our counter, it is possible to make measurements in points where the dose equivalent per pulse is greater than a few tenths of mrem/pulse.

With the two counters we have described it is possible to assure monitoring of all areas around our machines. Moreover, a third counter (i.e. a fission chamber) could be employed in the dose range not covered by the first two.

Normal fast neutron film-badges have also been used in integral measurements. However, it has to be pointed out that besides the usual defects of these detectors (often unsatisfactory precision, poor sensitivity, etc.), the biggest limitation in their use is the presence of the high background of X-rays. At points near the machine at least, blackening of the film makes it difficult to determine the response to neutrons. Of course, fast neutrons film-badges cannot be replaced in individual dosimeters.

Of smaller importance are the problems connected to the measurement of the photon dose, where integral detectors have always been used, such as film-badges and CaF_2 and LiF thermoluminescence dosimeters.

The intensity of X-rays emitted directly, around the Frascati machines at least, has proved to be very irregular, even when the experimental conditions seemed to be the same. Anyway, the exposure at a distance of some tens of centimeters (30–50 cm) from the machine walls has resulted of the order of 0.5 R per pulse in the average. Moreover, the energy emitted as X-rays per kJ stored in the capacitor systems has proved to be constant and the same for both machines. The average energy of these X-rays has been estimated to be of about 50 keV (MEROLLI *et al.*, 1973) by studying their absorption in aluminum by means of LiF TLD.

Conclusion

From the above exposition, it is evident that radiation levels caused by both neutrons and X-rays emitted by Plasma-Focus machines require machines to be shielded, especially when experimenters must be allowed to work near them, as happens very often.

The most difficult aspect of dosimetry is selection of instrumentations for neutron monitoring, which must satisfy some fundamental requisites imposed by the characteristics typical of the pulses from these machines. From our experience, we think that the Neutron Rem Counters and activated silver counters may be recommended, with proper adaptations.

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