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MRC-N-4

A PROPOSAL TO MEASURE EMP IN INSULATORS

27 July 1971

This Effort Supported by
DEFENSE NUCLEAR AGENCY
Under
DASA01-71-C-0105

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Whenever a directed gamma ray flux passes through a material medium, it is accompanied by a flux of Compton recoil electrons, which constitute an electric current. This current can be estimated as follows: Since the range of a Compton electron is about 1% of the Compton mean free path of the gammas, the flux of Compton electrons is about 1% of the gamma flux. Using the electron charge and expressing the gamma flux in Roentgens per second, one then finds

$$J(\text{amps/cm}^2) \simeq 3\times10^{-12}\,\dot{R}\,(\text{roentgens/sec}) \quad , \qquad (1)$$

For an illustrative number, at 100 meters from a one-megaton burst, we have

$$\begin{aligned} \dot{R} &\simeq 10^{15} \quad \text{R/sec} \\ J &\simeq 3000 \quad \text{amps/cm}^2 \end{aligned} \qquad (2)$$

Since no structure could be expected to survive at 100 meters from a megaton, the reader may wonder why EMP should be a concern here. The point is that EMP is induced before blast arrival, and voltages and currents may propagate on wires, cables, or other metallic carriers to great distances.

Over the last decade, many calculations have been made of the EMP induced in various geometries. One of the weak points in such calculations is in the treatment of media that are normally insulators, and the uncertainties become severe in locations where the gamma dose rate is high.

One important insulator is the air. Fortunately, due to decades of work on ionization, recombination, and electron mobility in air, we believe the electrical conductivity of the air can be calculated fairly well. Unfortunately, the same cannot be said for other common insulators, such as concrete, for example.

Normally, the physical problem is approximately the following. Suppose the Compton current J is being driven in a concrete slab. Since electrons are being displaced relative to the positive ions, an electric field E builds up. This electric field tries to push the Compton electrons, and any other free electrons, in the opposite direction to the Compton flux. The electric field will be limited by one of several possible effects.

First if E should exceed about 10^7 volts/cm, the range of the Compton electrons will be seriously reduced by the electric force on them. The range of the Compton electrons is normally a few mm in concrete, and they have energies of the order of Mev.

Second, the concrete will have some conductivity σ, especially in the presence of radiation. The electric field may build up until the conduction current σE just balances the Compton current, so that

$$E = J/\sigma \tag{3}$$

Thus if σ were 10^{-3} mho/cm, we would have

$$E = 3\times10^{6} \text{ volts/cm} \tag{4}$$

Of course, it is not likely that concrete would stand up electrically under such fields, especially in the presence of radiation. Experience in LASL Group J-14 indicates the best insulating oils will go only to about 3×10^4 volts/cm in Compton diodes (which present essentially the same physical problem). The question, of course, is: How does the electrical conductivity of the concrete (or other media) behave under intense gamma radiation?

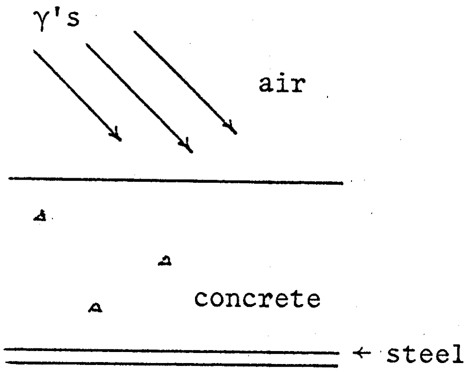
Third, we need to check that there is enough charge displacement to give fields of the order of 3×10^4 volts/cm. Assuming a dielectric constant of 10 , the capacitance C of one cubic centimeter of concrete is about 1 μμf . Therefore we need a charge displacement of

$$q = C\,E = 10^{-12}\times3\times10^{4}$$

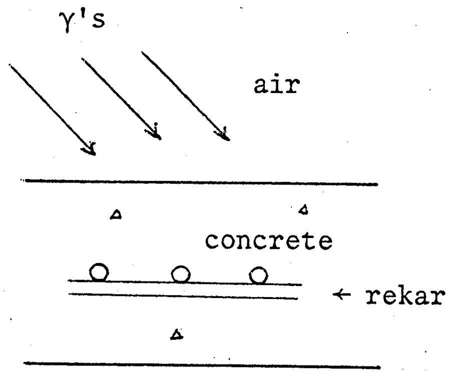
$$= 3\times10^{-8} \text{ Coulombs/cm}^2 \qquad (5)$$

Now the current 3000 amps/cm^2 flowing for 10^{-8} second displaces 3×10^{-8} Coulombs/cm^2 . Thus there is ample charge displacement in the example of Eq. (2). Actually, only 10^{12} R/sec for 10^{-8}seconds (i.e., 10^4 R) are needed to reach $E = 3\times10^4$ volts/cm .

It may be worthwhile to give a couple of practical examples of EMP problems involving concrete structures.



(a)

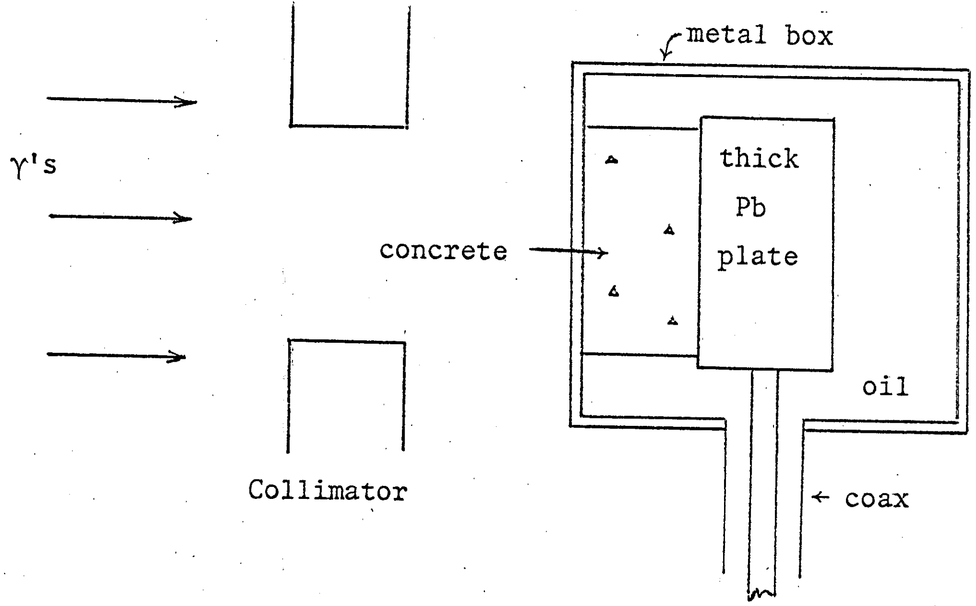


(b)

In example (a) (see sketch) we have a concrete slab with steel backing. In this example, the steel will collect most of the Compton current which enters it (the Compton current entering the air behind the steel plate will return to it). If the concrete is a good conductor, a return conduction current will flow back through it, leaving the steel plate with little net current. If the concrete is a poor conductor, the steel plate will collect a large current, which will seek the most convenient return path, such as entering conduits or grounds.

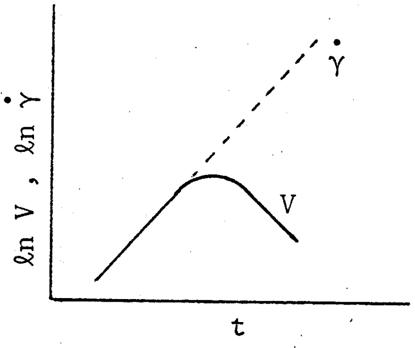
In example (b), the rebar in the concrete collects a current the magnitude of which will depend on the conductivity of the concrete. Again this current will seek the most convenient return path.

In order to estimate EMP generated in such structures, it would be very helpful to have experimental data on the conductivity of concrete under high dose rate and high fields. We propose here an experiment to obtain such data under conditions very similar to those in the examples above. The experiment involves replacing part of the oil in a Compton



diode with a sample of concrete. The central plate is made thick so that the Compton current leaving its back side is only a small fraction of that entering its front side. Design considerations include the following. We would like to subject the concrete to fields up to 3×10^4 volts/cm. If the concrete is 1 cm thick (probably a minimum acceptable), we need a voltage up to 3×10^4 volts to be developed. If the coax impedance is 50 ohms, 600 amps will flow into the coax. Thus the Compton diode needs to collect at least 600 amps of Compton current; let us call for 3000 amps. If the exposed area is 100 cm^2, we will want $J = 30$ amps/cm^2. From Eq. (1), we need $\dot{R} = 10^{13}$ R/sec. Then the charge displacement is ample to charge up the capacitance of the diode to 3×10^4 volts, provided the α of the gamma source is of the order of 1×10^8 sec^{-1}. To properly interpret the experiment, the gamma flux should also be measured.

Judging by past experience of J-14, the results should be as indicated in the sketch. At first the voltage V developed by the diode will rise with the gamma dose rate $\dot{\gamma}$. At some point, however, the voltage will pass through a maximum and subsequently decrease, even though $\dot{\gamma}$ continues to rise. This implies that the effective conductivity of the sample increases faster than linearly with $\dot{\gamma}$ (since $J \sim \dot{\gamma}$).



It should be noted that laboratory measurements of radiation induced changes in the conductivity of concrete have not gotten beyond the linear range, but stopped at dose rates several decades below the levels discussed here. However, with the Hermes accelerator, it appears that one could get into the lower end of the interesting range. Similar experiments should be tried on Hermes, with the hope that eventually most of the information might be obtainable in the laboratory.

Finally, a desirable feature of the simple experiment proposed here is that it closely duplicates the conditions of the practical EMP problem.