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RADIOACTIVE POISONS

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55

In addition to the explosive arrangement which has been recently discussed by Pryce[1], there are two other destructive mechanisms which can be based on U fission. Both of them are based on the power engine and they do not require the separation of the U isotopes or preparation of the element 94. [redacted]

1. M. H. L. Pryce, Reports B3 and B4

The first of these mechanisms is Szilard's "neutron ship". This is a ship or an airplane, driven by a U engine, which, naturally, looses a great many neutrons. These neutrons have a physiological effect in the surroundings.

The second mechanism is that of the radioactive poisons, [redacted] proposed also [redacted] in this connection by Professor G. Breit and E. O. Lawrence. This mechanism can be discussed more easily than Szilard's neutron ship and will be taken up first.

## RADIOACTIVE POISONS

A uranium power engine will create, as a by-product, a very considerable amount of radioactive materials. These radioactive materials can be extracted from the engine by flooding it with water or some other suitable solvent. The life time of the different radioactive substances varies between fractions of a second to about one day. The latter, long lived, substances are particularly dangerous since they can be transported to considerable dis-

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tances without loosing too much of their activity. They can be separated from the rest by chemical methods and distributed in powder form over a considerable area. They are particularly dangerous if they emit $\gamma$-rays which some of them probably do.

It has been estimated[2] that a power engine (working with unseparated or partially separated U) can develop $10^6$ kilowatts of energy. This is $10^5 \times 10^3 \times 10^7$ erg/sec or $10^{15} \times 10^5$ erg/day. One fission yields $4.8 \times 10^{-10} \times 1.6 \times 10^8/300 = 2.6 \times 10^{-4}$ ergs so that one has $10^{20}/2.6 \times 10^{-4} = 4 \times 10^{23}$ fissions per day. After one day's running of the engine, the number of radioactive atoms with a life time of one day will be, therefore, $4 \times 10^{23}$ multiplied by the number of these atoms per fission. Let us assume that the latter number is 1/4 (which is a low estimate) the efficiency of extraction 1, then, 1 day after the extraction one still will have about $4 \times 10^{22}$ radioactive atoms (about 6 grams). If each emits a $\gamma$-ray, this will be also the number of $\gamma$-rays at [redacted] disposal.

2. Halban and Kowarski's Report

The physiological effect of these $\gamma$-rays can be very crudely estimated by comparing it with the effect of X-rays.

Let us denote, for convenience sake, the intensity of X-rays which corresponds to 1R unit per second, as 1R[1] unit intensity. Such a unit creates in 1 ccm of air 1 electrostatic unit of ions of both charges per second. Since the mass absorption coefficient of air is about[3] .5 $cm^{-1}/gr\ cm^{-3}$ for X-rays of average hardness ($\lambda = .5A^o$), an air layer of 1 cm thickness absorbs

3. A. H. Compton and S. K. Allison, X-rays in Theory and Experiment. Appendix IX.

$.5 \times 1.3 \times 10^{-3} = .65 \times 10^{-3}$ of the total intensity. The X-rays which fall during a second on a $cm^2$, if their intensity is $1R^1$ unit, create, therefore, $1/.65 \times 10^{-3} = 1500$ e.s.u. of ions of both charges, i.e., $1500/4.8 \times 10^{-10} = 3.2 \times 10^{12}$ ions of both charges if they are totally absorbed.

About 100 R units over the whole body (i.e., an exposure of the whole body to X-rays of $1R^1$ unit intensity for 100 seconds) give very serious disturbances.[4] Since the X-rays are completely absorbed in the body,

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$3.2 \times 10^{12} \times 100 = 3.2 \times 10^{14}$ ions pairs per $cm^2$ of the body is about all a man can stand. Since 1 $\gamma$-ray of average, say 300 keV energy, gives $3 \times 10^5/45 = 7 \times 10^3$ ion pairs, the body cannot stand more than $3.2 \times 10^{14}/7 \times 10^3 = 5 \times 10^{10}$ $\gamma$-rays per $cm^2$.

If the radioactive material is spread on a horizontal plane, the number of $\gamma$-rays striking unit area of a vertical target is half as great as the number of $\gamma$-rays leaving unit area of the horizontal plane. Thus a man will be seriously injured if he stands on a plane each $cm^2$ of which emits during his sojourn there $10^{11}$ $\gamma$-rays. If the life time of a $\gamma$-active radioactive material is 1 day, it will emit during a day .63 $\gamma$-rays and a man cannot stand around for a day without protection in an area which contains more than $10^{11}/.63 = 1.6 \times 10^{11}$ radioactive atoms per $cm^2$.

Thus the $4 \times 10^{22}$ radioactive atoms which, according to our estimate, can be obtained per day from a power plant, suffice for seriously contaminating an area of $4 \times 10^{22}/1.6 \times 10^{11} = 25 \times 10^{10}$ $cm^2$ $= (5 \times 10^5\ cm)^2 = (5\ km)^2$. It is unnecessary to say that this is only a rough estimate and that the real area can be, perhaps, 10 times larger, or, perhaps, 100 times smaller.

PROTECTION AGAINST RADIOACTIVE POISONS

The absorption coefficients for $\gamma$-rays are given in the following table[5] in units of $cm^{-1}$.

5. W. Heilter, The Quantum Theory of Radiation, p. 215.

| | 50 keV | 100 keV | 250 keV | 500 keV | 1000 keV |
|---|---|---|---|---|---|
| Air | $2.2 \times 10^{-4}$ | | $1.45 \times 10^{-4}$ | $1.1 \times 10^{-4}$ | $.8 \times 10^{-4}$ |
| Water | .19 | .15 | .12 | .095 | .07 |
| Al | .85 | .44 | .29 | .22 | .16 |
| Cu (or Fe) | | | 1.1 | .7 | .5 |
| Pb | | | 4 | 1.7 | .80 |

These numbers show that the difficulty of protection increases greatly with increasing hardness of the $\gamma$-rays. This holds, fortunately, also for the personnel carrying out the contamination and presumably prevents the use of any radioactive material with $\gamma$-rays above 300 keV.

Let us assume that the personnel is at a distance of 10 meters from the radioactive material. The number of $\gamma$-rays per $cm^2$ at this distance will be $4 \times 10^{24}/4\pi \times 10^6 = 3 \times 10^{17}$ per $cm^2$. For safety, this number should be multiplied by at least 10 since the intensity is greater at the beginning of the trip than at the arrival at the destination. Since one can stand $5 \times 10^{10}$ $\gamma$-rays per $cm^2$, the protection must decrease the intensity by a factor $3 \times 10^{17} \times 10/5 \times 10^{10} \sim 10^8 = e^{16.4}$. For 250 keV energy $\gamma$-rays, 4 cm of lead would be sufficient for this. Taking a chamber of 100 cm x 100 cm x 200 cm, this requires $10 \times 10^4 \times 4\ cm^3 = 4 \times 10^5\ cm^3$ or $4.5 \times 10^6$ gr = 4500 kg lead. This could be reduced by about a factor two by placing part of the shield around the radioactive material, rather than around the personnel.

The simplest protection in the contaminated area probably consists in washing the radioactive material under the ground. A depth of 5 cm probably suffices to reduce the activity under the critical amount. In towns, the water would carry the radioactive material into the sewage system. The washing crew should operate from well armored tanks--an armor of 2-3 cm iron seems adequate. It is fortunate that the whole danger disappears in a couple of days and that it can be detected with relative ease by placing electroscopes at street intersections or other appropriate points.

This method of protection is impossible while the material is floating in the air. However, during that time it may be dispersed by wind and the inside of buildings with filtered air-intake remains safe. If the radioactive material is not uniformly distributed but left in relatively large chunks, some of these chunks may escape detection and cause considerable damage before they are either detected or before they decay naturally.

THE NEUTRON SHIP

The difficulties connected with the construction of a neutron ship are naturally greater than those connected with a stationary heat engine. Supposing that these difficulties can be overcome, one can assume that the power of the engine of the neutron ship is about 1/10 of the power of the stationary engine. The number of neutrons which the machine can emit and still keep functioning can be estimated to be 1/20 per fission. This gives $N = 8 \times 10^{18}$ neutrons per second available.

The macroscopic absorption coefficient $\varkappa$ of air is $\varkappa = 1.7 \times 10^{-4}\ cm^{-1}$. The density of neutrons in free space would be $\frac{\varkappa^2 N}{4\pi v \sigma_a} \frac{e^{-\varkappa r}}{r}$ where v is the velocity of the neutrons $\sigma_a = 1.2 \times 10^{-24} \times 3/4 \times 2.7 \times 10^{19} \times 273/293 = 4.5 \times 10^{-5}\ cm^{-1}$ the absorbing cross section per ccm, N the number of neutrons generated at the source per second, r is the distance from the source. The stream of neutrons per $cm^2$ is $\frac{N}{4\pi r^2}(1+\varkappa r)e^{-\varkappa r}$.

The physiological action of a neutron is about as strong as that of 20 $\gamma$-rays of 300 keV energy. Thus a man is endangered if he is exposed to $5 \times 10^{10}/20 = 2.5 \times 10^{9}$ neutrons per $cm^2$. Let us assume that the time of exposure is t, sec, then the danger point is reached if $N(1+\varkappa r)e^{-\varkappa r}t/4\pi r^2 = 2.5 \times 10^9$, i.e. if $(t/r^2)(1+\varkappa r)e^{-\varkappa r}$ reaches the value

$$12.6 \times 2.5 \times 10^9 / 2 \times 10^{16} = 1.6 \times 10^{-6} \text{ sec/cm}^2.$$

Assuming a velocity of 360 km/hour = $10^4$ cm/ sec for the plane, we can estimate $t = 10^{-4}$ r if the plane passes the object once. For n passages we have $t = 10^{-4}$ nr or $r = 60n\,(1+\varkappa r)e^{-\varkappa r}$ cm. This is, of course, a very short distance for n = 1 so that it appears, off hand, that the neutron ship does not constitute a serious danger.

It must be admitted, however, that our estimates may be considerably in error. Also, the pilot could, for short times, produce bursts of neutrons by releasing much greater numbers of neutrons. Such bursts could be produced by removing the scattering shield of the engine.

An adequate protection of the pilot against the neutrons could be provided by a very thick (about 100 cm) water shield. Protection of the target is, on the other hand, much more difficult than in the case of radioactive poisons because there is no time for washing away the poison but the protection must be present at the time the ship flies over. The protecting shield, if present at the flight of the neutron ship, could be a quite thin ( a couple of cm thick ) sheet of a hydrogeneous material or any other neutron absorbing substance.

On the whole, it appears that the neutron ship constitutes a less serious menace than the radioactive poisons. The reason for this is essentially that it appears to be difficult to concentrate its action for a sufficiently long time to a relatively small area.

The working of both mechanisms deserves a more detailed study than given in these pages. With respect to the radioactive poison mechanism, which constitutes a more immediate threat than that of the neutron snip, a knowledge of the $\gamma$-radiation of the long lived fission products would be valuable.

**Recommendations:**

(a) Research on $\gamma$ radiation of fission products is suggested.

(b) Arrangements for the manufacture of electroscopes in sufficient numbers to serve as detectors of radioactive poisons at important points should be considered.

(c) Separation of radioactive materials from other materials in the power plant should be investigated.