R290257

ES1/4127R

This document does not necessarily represent the final views of A.W.R.E. or the Mathematical Physics Divisions.

Theoretical Physics Note No. 78/65

Expected radioactivities from Plowshare devices

[redacted]

[redacted]

[redacted]

October, 1965

023387
TD001/999

1. Introduction

A Plowshare device will produce fission products, residual tritium, and neutrons of various energies. This note assesses very roughly the relative amounts and importance of these sources of radioactivity, assuming that the simplest of measures have been adopted to reduce the radioactivity i.e. a device getting most of its energy from fusion, and surrounded by a neutron absorber [redacted]. Our purpose is merely to get a preliminary idea of which source of radioactivity stands most in need of reduction.

In view of this very limited aim we choose the simplest possible basis for comparing the various radioactivities, viz. the energy emitted from 1 hour after the explosion to infinite time. This gross simplification ignores such obvious points as the difference in biological hazard between, say, the low energy beta particles from the residual tritium and the gamma rays from fission products. Such points are part of the health physics problem of establishing a proper quantitative basis for comparison of the biological hazards associated with the various forms of radioactivity.

2. Neutrons

[redacted]

[redacted]

3. Neutron induced activity in soil

The neutrons emitted from the device will mostly be absorbed in a neutron shield designed to give stable products after neutron capture. But some neutrons will penetrate the shielding and will eventually be captured in the surrounding soil or rock. Some of these absorptions result in radioactive products, which, we must assume, will later be mixed with the rest of the debris from the device and represent an additional potential hazard.

To make some quantitative estimates we take the chemical composition of the environment to be that of [redacted] This composition contains [redacted] and we have calculated the amounts of the radioactive products of these elements produced by [redacted] The nuclides which contribute significantly are [redacted] Results are given below for unit neutron flux entering the soil. The column headed "Radiation" gives the type, energy in MeV and, in brackets, the percentage of disintegrations resulting in each particle or photon emission. The beta energies quoted are maxima; [redacted]

Nuclide	Half life	Radiation	[redacted]	
		[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	-
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
		[redacted]		
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
		[redacted]		
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
		[redacted]		
[redacted]			[redacted]	[redacted]

It should be noted that the choice of 1 hour as the earliest time of interest leads to the exclusion of certain short-lived products, notably 2.3 min Al^{28}, which would contribute at time zero but have become negligible after 1 hour.

As a rough guide to the influence of differences in composition we give below a comparison of the percentages of neutrons captured in Norwegian Loam and Plateau Basalt, for which data are given by Miskel (1964) in Proceedings of the Third Plowshare Symposium, p.157.

Percentage of neutrons captured in Norwegian Loam and Plateau Basalt

Element	Si	Ti	Al	Fe	Mn	Mg	Ca	Na	K	H	P	S
Loam	17.7	6.5	8.0	26.4	2.3	0.6	2.7	3.7	19.4	12.4	0.07	0.2
Basalt	12	14.8	2.8	43.4	2.5	9.7	6.7	4.1	1.3	2.8	0.08	-

Only in the cases of Mg and K are there order of magnitude changes in going from one medium to the other. The active nuclide of Mg is Mg^{27} which has 9.5 min half life and has completely negligible effect at 1 hour. The effect of the change in proportion of K may be readily seen from the figures presented above.

For the loam we find that the beta energy emitted from 1 hour to infinite time is

$$B_1 = 3.7 \times 10^{21} \psi \text{ MeV kt}^{-1}$$

and the gamma energy is

$$G_1 = 1.8 \times 10^{22} \psi \text{ MeV kt}^{-1}$$

Neutrons are assumed to be emitted at [redacted]. Of those emitted, a fraction ψ penetrates the shield and reaches the soil.

4. Residual tritium

[redacted] The half-life of tritium being 12.4 years, an initial gram has, at t seconds later, a disintegration rate of

$$0.3546 \times 10^{15} \exp(-0.1773 \times 10^{-8} t) \text{ dis. sec}^{-1} \text{ g}^{-1}.$$

Taking the average energy of emitted beta particles [redacted]

And the energy from [redacted]

5. Fission products

A kiloton of fission energy results from [redacted]. For times greater than [redacted], the rates of emission of [redacted] from the [redacted] each being given roughly by

[redacted]

6. Comparisons

6.1 We can now compare the radioactivities arising in various ways. Since we are interested in the activity that escapes from the crater, rather than the amount created, it is convenient to define [redacted] as [redacted] and similarly [redacted] Denote the [redacted] according as the source is fission products, residual [redacted] induced [redacted]. Let the [redacted] Then the energies that [redacted]

from fission products,

[redacted]

and from induced activity in soil,

[redacted]

Hence we have

[redacted]

(Recall also that [redacted])

6.2 Suppose there is no neutron shield, and the three escape fractions [redacted] have a common value. Then

[redacted]

Hence for [redacted] the activities from fission products and neutron capture in soil are of [redacted] by about [redacted] As the ratio [redacted]

6.3 It is conceivable that schemes for deliberately retaining radio-activity in the ground will be [redacted]

Thus for [redacted] there is little point in striving to make [redacted]. And conversely if the [redacted] least attainable value of [redacted] there is little point in striving to reduce [redacted] below [redacted]. (Of course arguments about the [redacted])

6.4 Taking [redacted] of [redacted] as being about the best that is likely to be practicable, and taking the neutron output of section 2 as representative, we find the shield transmission factor ψ to be about [redacted] If the escape fractions have a common value we find

[redacted]

Thus for [redacted], the predominant feature is beta and gamma energy from fission products, followed by beta energy from tritium and gamma energy from induced activity, leaving beta energy from induced activity as least important of all. Hence further shielding is scarcely worth while. Indeed, halving the [redacted] leaving [redacted] and the fission product contribution dominant.

7. <u>Summary</u>

From the relations

[redacted]

and [redacted] we can trace something of the process of minimising the hazard of escaping radioactivity.

7.1 Stage 1. Here we assume a moderately clean device, no neutron shielding, and all escape fractions equal. The relations

[redacted]

suggests that we ought to try to achieve [redacted] but indicates that there is not much point in striving to reduce the ratio further unless we also include some neutron shielding.

7.2 Stage 2. Here we include neutron shielding ([redacted]) that will give [redacted] but we still assume [redacted]. From the relations

[redacted]

we conclude that, with this level of neutron shielding we ought to ensure that [redacted]

7.3 Stage 3. Here we assume that, in addition to neutron shielding sufficient to make [redacted], we can [redacted], but not the residual [redacted], i.e. [redacted] but [redacted] From

[redacted]

striving to have

[redacted]

Thus, [redacted] The deduction would seem to be that, with this degree of neutron shielding, selective retention of fission products is not worth while unless [redacted] If [redacted] selective retention of fission products becomes worth while only if the neutron transmission factor [redacted] is reduced from [redacted] which would require [redacted]

The apparent conclusion is that anyone striving to make [redacted] while having a device in which [redacted] must be contemplating [redacted]. One weakness in this deduction is that, because of the [redacted], it may be legitimate to [redacted] not included in our simple basis of comparison. Similarly the [redacted] because it [redacted].

In fact what is illustrated here is the danger of reading too much into the extremely simple relations obtained in this note. Mention has already been made of the great simplification inherent in using the [redacted] Among further complications, no doubt an important one is the [redacted].

For all these reasons the conclusions that can be drawn from the present treatment must be regarded as very tentative and subject to much qualification.

Distribution:

[redacted]