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THE DETECTION OF A SUPER EXPLOSION

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THE DETECTION OF A SUPER EXPLOSION

I. Basic Assumptions

We shall arbitrarily choose as a basis for discussion a thermonuclear reaction (initiated by a fission reaction) giving about one thousand times as much energy release as the present fission bombs. We shall assume the following D-D reactions to go with equal probabilities:

$$ {}_1H^2 + {}_1H^2 \longrightarrow {}_1H^3 + {}_1H^1 + 4.0 \text{ Mev} $$

$$ {}_1H^2 + {}_1H^2 \longrightarrow {}_2He^3 + {}_0n^1 + 3.3 \text{ Mev} $$

The tritium produced in the first reaction will react with deuterium as follows:

$$ {}_1H^3 + {}_1H^2 \longrightarrow {}_2He^4 + {}_0n^1 + 17.6 \text{ Mev} $$

The overall reaction we shall assume is, therefore:

$$ 5\ {}_1H^2 \longrightarrow {}_2He^4 + {}_2He^3 + {}_1H^1 + 2\,{}_0n^1 + 25 \text{ Mev} $$

In particular, we shall assume that we start with 2×10^{29} deuterium atoms, and that the reaction goes to completion so that 8×10^{28} neutrons are released. We shall further assume that practically all of these neutrons get slowed down to thermal energy before reacting with the atmosphere.

In this report we will consider the possibility of detecting such a super explosion if it were set off in the atmosphere; we will not

report; A^{41} has such a short half-life (1.83 hours) that it will decay far too rapidly to allow its use for detection purposes. We are left with C^{14} and A^{37}, and we will now proceed to show that these active nuclides look very promising.

III C^{14} and A^{37} Activities.

We have seen that a super releasing 8×10^{28} neutrons will give rise to 1.8×10^{19} d/m of C^{14} and 8.3×10^{19} d/m of A^{37}. These amounts of activity will suffice for the detection of a super if

a) the amount of each activity already present in the atmosphere (from the reaction of cosmic ray neutrons on N^{14} and A^{36}) is not too great, and

b) if the specific activity of the sample being counted is great enough so that the observed counting rate is sufficiently above the counter background. Clearly, the exact value of the specific activity depends on the extent to which the super induced activities are spread throughout the atmosphere at the time a sample is taken for analysis. We shall make the pessimistic assumption that mixing with the atmosphere is complete.

If we take the mass of the atmosphere as 5.2×10^{21} grams(2) or 1.8×10^{20} moles, and the mole fraction of CO_2 in air as 3×10^{-4} then there are 5.4×10^{16} moles of CO_2 or 6.5×10^{17} grams of C in the entire atmosphere. The specific activity of natural C has been measured,(3) and is 15 d/m/gram. Therefore, the C^{14} activity in the entire atmosphere is 1×10^{19} d/m, or about half the super produced activity.

(2) Handbook of Chemistry and Physics, 29th Edition, p. 2579; Chemical Rubber Publishing Co., 1935

(3) E. C. Anderson, Thesis, University of Chicago, June 1949. Libby, Anderson and Arnold, Science. 109, 227 (1949). The value reported in these papers has since been raised slightly by recalibration of the counters used.

In order to calculate the A37 activity already present in the air, we will assume that the total amount of C^{14} and A^{37} in the world is in secular equilibrium with the rate of production from cosmic ray neutrons. The CO_2 in the air is estimated to contain only 1.5% of all the earth's exchangeable carbon(4) so $\frac{6.5 \times 10^{17} \text{ g}}{0.015} \times 15 \text{ d/m/g} = 6.5 \times 10^{20}$ d/m is the C^{14} activity of the whole world, hence is the rate of production of C^{14} atoms from cosmic ray neutrons. (This may be compared with the value 6.2×10^{20} min^{-1} calculated for the slow neutron flux in the atmosphere using the most recent direct measurements with BF_3 counters.) The rate of production of A^{37} is 7.6×10^{-5} of the C^{14} rate (Table I, column 6), hence the total A^{37} activity is 4.9×10^{16} d/m, compared to the 8.3×10^{19} d/m formed by a super reaction.

Table III summarizes the above conclusions, together with some calculations of expected specific activities.

TABLE III

Active Nuclide	Moles Carrier	Activity in Atmosphere from Cosmic Ray neutrons d/m	Activity from Super d/m	Specific Activity from Cosmic Rays d/m/mole	Specific Activity from Super d/m/mole
C^{14}	5.4×10^{16}*	1.0×10^{19}	1.8×10^{19}	180	330
A^{37}	1.7×10^{18}	4.9×10^{16}	8.3×10^{19}	0.03	50

* As CO_2

It can be seen that for A^{37}, the contribution from activity produced by cosmic ray neutrons is negligible, and indeed would not be important even

(4) See Reference No. 3.

if the super induced A^{37} were lowered by a factor of 100.

The same cannot be said for C^{14} if, as assumed, the activity ends up in the CO_2 molecule. A smaller super than we have assumed might still be detected by C^{14}, however, because Table III was based on the assumption that all of the C^{14} produced had mixed with the earth's total atmosphere. Furthermore, there is no evidence that all of the C^{14} will end up as CO_2. The CO content of air is not well known, but probably is very low; if a fair fraction of the super induced C^{14} is present as CO the situation becomes very favorable because practically all of the cosmic-ray induced C^{14} is present as CO_2. Experimental work on this aspect of the C^{14} problem is necessary.

The question still has to be answered of whether or not the samples collected are "hot" enough to count above the counter background. For purposes of discussion let us assume that the gases collected for counting are CO_2 and argon, and that the samples are to be counted in a gas-filled proportional counter at one atmosphere pressure and a volume of 2.24 liters (or 0.1 mole). (Other measuring techniques are also possible; the above is chosen merely as a specific, practical example). We see from Table III that 0.10 mole of CO_2 would have an activity of 33 d/m from super induced C^{14} and 18 d/m from cosmic ray induced C^{14}. The counter background, estimating from past experience with C^{14} counters, would be about 15 c/m. Therefore no trouble should be encountered in using C^{14} for detecting a super giving 8×10^{28} neutrons. Similarly, 0.10 mole of argon would have a super induced activity of 5 d/m, the cosmic ray induced argon activity being negligible. The counter background can only be

produced by the action of neutrons on He^3 in the atmosphere. It might be argued that some tritium would be formed by the action of neutrons on He^3 produced in the other D-D reaction. While some tritium might be produced in this manner, the amount will not be large, since the cross section is high only for thermal neutrons, and much of what is formed will further react with deuterium.

Even if the above calculations are correct there still remains the problem in what chemical species the tritium will finally be found. It could be present for example as water, ammonia (which exchanges rapidly with H_2O) or elementary hydrogen. If we assume that the tritium is as water, then we can calculate a specific activity. Of the 1.8×10^{20} moles of air, from 10^{-2} to 10^{-3} is water vapor. Taking 5×10^{-3} as the mean mole fraction, there are 9×10^{17} moles of water vapor in the entire atmosphere. If we assume that the tritium mixes completely with the earth's atmosphere (and that is does not precipitate) then the specific activity of the water will be 3×10^{19} d/m $\div$ 9×10^{17} moles = 33 d/m/mole. About the most that can be said about the use of tritium for detection purposes is that one would not rely on it but might as well look for it.

V Deuterium.

The mole fraction of H_2 in the atmosphere is 5×10^{-7} and of water vapor about 5×10^{-3}. Therefore, of the 1.8×10^{20} moles of air, 9×10^{13} moles are H_2 and 9×10^{17} moles are H_2O. Since the abundance of deuterium in natural hydrogen is 0.02%, we have 1.8×10^{10} moles of deuterium or 2×10^{34} atoms of deuterium present as the element in the entire

deuterium (as D_2). Therefore, the use of deuterium for detecting a super, particularly an unsuccessful super, is not completely out of the question, especially if the HD (and D_2) content of the atmosphere is very constant.

VI. He^3

If a super gave 4×10^{28} He^3 atoms, and atmospheric mixing were complete, these He^3 atoms would be added to $\sim 7 \times 10^{32}$ atoms of He^3 already present. If the mixing were only with 1% of the earth's atmosphere, then one would be adding 4×10^{28} atoms to 7×10^{30} atoms, or the He^3 content would increase by about 6 parts in 10^3. This increase could be detected only if the He^3 to He^4 ratio in atmospheric helium were very constant.

VII. Detection of Preliminary Thermonuclear Experiments.

The foregoing discussion was limited to a full-fledged super. It is quite conceivable, however, that before such a super were tried, preliminary experiments would be done on thermonuclear reactions. In particular, one would want to look for evidence that the ignition of deuterium-tritium mixtures had occurred.

We have seen that the most promising method of detecting a super depends upon looking for radioactive nuclides formed by reactions of the large number of neutrons emitted by a super. Detection methods based on analyses for deuterium, tritium, and He^3 do not look hopeful for a super, and are correspondingly worse for a small thermonuclear reaction (unless, of course, a sample of air could be obtained quickly from the immediate vicinity of the explosion). However, one other possibility exists of