This document consists of 49 pages.
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ANALYSIS OF JOE-4 (u)

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Report by: H. A. Bethe

I. DATA

The data were transmitted to us through the courtesy of [redacted] b(1)
They were obtained at various [redacted] laboratories, as well as Los Alamos and b(1)
Argonne. The data fall into three classes:

(1) Mass spectroscopic: these are the most reliable data.

(2) Radiochemical: these are less reliable because there was [redacted] At present, [redacted] b(3)

(3) Seismic and acoustic: these are much less accurate but are the only ones which give the yield (rather than the efficiency).

(1) Mass Spectrograph Data

Three uranium samples were analyzed by Fried et al at Argonne.
The isotopic constitution was (in percent):

TABLE I

U	233	234	235	236	237	238
A	[redacted]					
B						
C						

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Sample A is less accurate than the others but concordant with them after subtraction of the blank. Since C has the smallest experimental errors, it was in general used as the basis of our calculation even though it contained more blank uranium than B.

Isotopic analysis of Pu gave, in percent of total Pu:

TABLE II

238	239	240	241
[redacted]			

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All numbers are corrected for radioactive decay or build-up since shot time; e. g., Pu^{239} represents the amount which will ultimately exist after all Np^{239} has decayed.

A preliminary isotopic analysis of Li has been made. [redacted]

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(2) Radiochemical Data

[redacted]

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[redacted] b(

(3) Seismic and Acoustic Evidence

The best evidence on yield comes from seismic data. The indicated yield is between [redacted] apparently with very few stations giving results near the upper limit, and the bulk lying between [redacted] b(3 b(

Most recent analysis seems to narrow the limits of error and gives [redacted] megatons as the most likely number.

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Acoustic data have given greater scatter for the yields of our own bombs. They seem to indicate a somewhat lower yield. [redacted]

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II. GENERAL CONCLUSIONS

[redacted]

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This will be discussed in detail in Section III.

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[redacted]

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[redacted]

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III. THE AMOUNT OF U^{235}

[redacted]

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To this has to be added the 235 destroyed through fission, (n, 2n) and (n, γ) reaction.

To estimate the fissions in 235, we first estimate the <u>total</u> fissions (in 238 <u>and</u> 235) as a fraction of the total uranium found in samples B and C. This can be done through the measurements of U^{237}.

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Therefore, we shall in the following treat this number seperately from the more certain numbers derived from mass spectrograph analysis.

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The fissions in 238 will be estimated in Section VI.

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The 236 can be formed in two ways, namely either from 235 by neutron capture or from 238 by an (n, 3n) reaction.

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Some of this should be attributed to the

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thermonuclear reaction itself.

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[redacted] Indeed, the cross section for fission of Pu^{239} by 14-Mev neutrons is slightly smaller than that of U^{235}. Therefore, the (n, 2n) cross section is likely to be somewhat larger for Pu. [redacted]

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V. AMOUNT OF U^{238}

This amount can be deduced from the amount of 239 and the ratio of 240 to 239.

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[redacted] b(3)

[redacted] The latter number is probably more accurate and will, therefore, be used.

The ratio of U^{238} to U^{239} is $1/k$ times the measured ratio of U^{239} to U^{240}.

[redacted] b(3)

This is a very ressonable fraction and would indicate that about three-fourths of the sample was due to air contamination.

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VI. FAST NEUTRON REACTIONS IN 238 AND 235

Nordheim in TM-47 has investigated the behavior in U^{238} of neutrons originating from a thermonuclear reaction.

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The drop in (n, 2n) cross section with energy should almost certainly be attributed to the inset of an (n, 3n) reaction.

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TABLE V

Fissions in Tuballoy (per Thermonuclear Neutron)

[redacted]

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However, if the tuballoy has finite thickness, the secondary fissions will in fact be somewhat more reduced than would follow from TM-47. [redacted]

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[redacted] b(3)

This correction is obviously small; no correction was applied for this burn-up.

The (n, 2n) cross section in 235 can be estimated from the measured fission cross section of 2.2 barns and the total inelastic cross section of 2.73. In this case, it is reasonable to assume that (n, 3n) reaction cannot take place at 14 Mev. The theoretical reason for this is that 235 contains fewer neutrons than 238 and, therefore, the sum of the binding energies of the first two neutrons is likely to be greater than for 238. Thus the threshold for (n, 3n) should be higher. [redacted] b(3)

It is reasonable then to assume that the (n, 2n) cross section is about .5 barns. Its ratio to the (n, 2n) for 238 is, therefore, 1/2.3. b(1)

[redacted] b(3)

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If 235 and 238 were both infinitely thick and were exposed to the same flux of high energy neutrons, then the ratio of 234 to 237 should be equal to the product of the ratio of cross sections and the ratio of areas.

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[redacted] Better estimates will be given in Section XI.

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We must now investigate the fate of neutrons of fission energy formed in the uranium. Some of these will remain in the uranium, some will diffuse back on the side on which they entered, and some will escape on the outside of the uranium. To estimate these various fractions we proceed as follows.

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The diffusion of the post-inelastic neutrons was treated in a similar manner as in TM-47 with two exceptions. One was that the finite thickness of Tu was taken into account and thus the neutron density represented by a term with e^{Kz}, as well as a term with e^{-Kz}, the notation being the same as in TM-47. The second difference was that we took into account the extrapolated endpoint correction on both surfaces of Tu. [redacted] b(3)

All these calculations were done assuming plane geometry similarly to TM-47. The results are given in Table VI as a function of the thickness of the Tu.

TABLE VI

[redacted] b(3)

On this basis we have calculated the two lines labelled thermal neutrons absorbed in Table VI. Adding the absorption of post-inelastic neutrons, we then obtain the lines labelled total neutrons absorbed.

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IX. GEOMETRY AND THERMONUCLEAR EFFICIENCY

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[redacted]

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b(3

Using the volumes calculated in Table VII, we can then calculate the temperature which can be established in the cavity inside the Tu. [redacted]

From this formula plus a correction for material energy the temperatures in Table IX are derived. [redacted]

[redacted] This is, of course, due to the much larger volume over which the energy has to be distributed in the latter case. [redacted]

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TABLE IX

Temperatures, Reaction Rates, Pressures, Motion

*1 kilojerk = 10^{19} ergs, 1 kiloton = 4 kilojerks.

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[redacted] b(3

We can also estimate pressures which were developed in the thermonuclear reaction. [redacted] b(3 This gives finally the time available for the thermonuclear reaction, which is also listed in Table IX, and which agrees in order of magnitude with the times we have previously used.

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[redacted]

XIII. SUMMARY

It must again be emphasized that the conclusions reached in this report are subject to considerable doubt. It is a bold undertaking, indeed, to determine both the composition and the geometry of a bomb which you have never seen, merely from the radiochemical debris resulting from it. In addition, fractionation may have falsified the samples and important ingredients may have been missed. [redacted]

In addition to this note of general skepticism, it is important to remember that certain conclusions are much more firm than others. Thus the ratio of total fissions to 235 invested and the distribution of fissions may be considered as well established. On the other hand, the arguments about the dimensions of the bomb are considerably less certain.

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The findings establish beyond doubt that the Russians have a capability to produce U^{235} in quantity.

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They do not establish for certain that this device is deliverable but nothing in the findings precludes this possibility.

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However, the yield they have achieved is certainly enough to cause concern.

H. A. Bethe
Hans A. Bethe

HAB:li

September 11, 1953

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