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A REVIEW OF POTENTIAL RADIONUCLIDES PRODUCED IN WEAPONS DETONATIONS

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ABSTRACT

Estimates have been made of what the probable radionuclides produced in weapons detonations, including fission products and neutron-induced radionuclides in air, soils, and sea water will be. The nuclear and decay properties and some metabolic or biological properties of these nuclides are tabulated where available. Estimates are made of the amounts of the radionuclides produced in weapons detonations. Some radionuclides are discussed with respect to their particular biological interest from the standpoint of the hazard to man.

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A REVIEW OF POTENTIAL RADIONUCLIDES
PRODUCED IN WEAPONS DETONATIONS

INTRODUCTION

The question often arises as to whether or not a particular nuclide produced from weapons detonations is a potential hazard and would therefore merit particular study. Some fallout studies have included analyses for ^3H , C^{14} , Sr^{89} , Sr^{90} , I^{131} , Cs^{137} , Ba^{140} , Ce^{144} and a few others. The relative and absolute importance of these nuclides are dependent on certain assumptions as to their biological effects at low concentrations for which no conclusive evidence exists. Future studies may indicate differences in their biological importance. The purpose of this report is to present information which can be used in studies involving the internal hazards of radioactive fallout.

A number of observations and investigations associated with the testing of large nuclear weapons, especially those involving thermonuclear processes, have indicated the potential biological importance of neutron-induced radioactivity in weapons materials, air, soils and sea water under certain conditions of detonation. These induced radioactivities become more important with increase in thermonuclear yield of weapons relative to the fission product yield and some may well become biologically important with an increase in their production.

Because of the wide range of conditions which may exist in connection with nuclear detonations, it does not appear feasible to determine the absolute biological importance of each of the nuclides potentially present following a detonation. It is possible to present conditions under which virtually any radionuclide produced with half-lives longer than a few seconds would be a potential hazard. In this respect nearly all of the radionuclides produced are to be considered hazardous. Some of the conditions which may vary are rate of testing, fission to fusion ratio, detonation characteristics (such as height or depth of burst over sea or land), type of soils involved, neutron fluxes and energies, weapons constituents, biological factors and time after detonations. No attempt is made to list all of the radionuclides in order of biological importance. Such an objective is inherently questionable and is not the reason for preparing this review.

The relative biological importance of nuclides from the standpoint of the hazard to man may be assessed from some of their physical and chemical properties as well as from their metabolic properties. From the standpoint of their presence in tropospheric vs. stratospheric fallout, certain nuclides would be relatively more important, although this type of consideration

*Not listed in order of importance.

would not constitute exacting criteria to delineate individual nuclides. Of particular interest here are the abundances of the various nuclides with respect to time. An attempt has been made to estimate the amounts of each nuclide produced per megaton of yield from weapons detonations. For each category it has been attempted to estimate which nuclides are involved, their nuclear or decay properties and their abundances at various times from detonation to one year.

Appendix E contains a summary of much of the available biological data of interest here. These data include certain metabolic properties and maximum permissible concentrations from the recommendations of the International Commission of Radiological Protection (ICRP)(1).

THE FISSION PRODUCTS

It is generally agreed that Sr^{90} and Cs^{137} produced in the fission process are potentially important so far as hazards to man are concerned, especially from the standpoint of long-term, worldwide fallout. Sr^{89} , I^{131} , Ba^{140} and Ce^{144} are considered by many to be of biological interest at short or intermediate times following detonations. A large number of studies and investigations have been made with reference to some of these nuclides and a few others, reference to which would be voluminous (a general review and bibliography may be found in reference 2). Other fission products may be biologically important also.

Most of the known or postulated fission products have been considered here. For this purpose the data of Bolles and Ballou (3) for slow neutron fission of U^{235} have been used. The fission process found in nuclear weapons may differ from these data, but probably not by more than a factor of two, which is of minor consequence when considering the over-all uncertainties connected with the hazard to man. In Appendix A are tabulated all of the fission products, their nuclear and decay properties so far as they are available; decay chains (3, 4, 5) and estimates of their abundances at various times from the time of fission to one year.

RADIONUCLIDES PRODUCED IN AIR

Radionuclides may be produced in air through neutron reactions following nuclear detonations. The (n, γ) , (n, p) and $(n, 2n)$ reactions occur because of the wide range of neutron energies that exist in these detonations. Other high order reactions, such as (n, d) and possibly others, also occur but probably at very low relative frequency. In Appendix B, Part I, an attempt has been made to tabulate possible resulting nuclides from neutron reactions in air, with their nuclear and decay properties. In Part II of Appendix B are estimates of the radioactivities present at various times up to one year after a nuclear detonation in air.

RADIONUCLIDES PRODUCED IN SOILS

When nuclear weapons are detonated so that appreciable numbers of neutrons are available for reaction with constituents of soils, a number of radionuclides may be produced. The primary reaction of interest is that of (n, γ) , involving slow neutrons, although others occur to some extent. In Appendix C are given estimates of the nuclides to be expected and their nuclear and decay properties. Estimates of the amounts produced and abundances at various times up to one year after detonation are given in Part II of Appendix C. The methods and assumptions used are also shown.

RADIONUCLIDES PRODUCED IN SEA WATER

When nuclear weapons are detonated so that resulting neutrons are available for reaction with the constituents of sea water a large number of radionuclides are induced in sea water. These radionuclides are considered in Appendix D and their nuclear and decay properties are tabulated. Many of these nuclides also appear in the other major categories previously discussed. Estimates have been made (Part II, Appendix D) of the quantities of radionuclides induced in sea water based on an underwater burst where all of the available neutrons are captured in sea water.

RADIONUCLIDES PRODUCED IN OTHER MATERIALS

Some radionuclides have been found in fallout samples which may have their origin in soils, sea water or materials near the site of detonations during weapons tests or in some way associated with particular detonations. A combination of sources may provide detectable amounts of some of these nuclides in weapons debris although their specific origins are not apparent. No detailed discussion of these nuclides is included here. A number of studies include data or estimates of Pu^{239} production in weapons detonations (6, 7). A considerable amount of investigation and study has been made of the biological hazards of this nuclide (8). Isotopes of Co, Zn, Fe and Mn have been found in weapons debris (9 - 14) the origin of which probably includes a combination of categories.

SOME RADIONUCLIDES OF PARTICULAR BIOLOGICAL INTEREST

As an example of a rationale using the information tabulated in this review it may be of interest to estimate some of the radionuclides produced in weapons detonations which may be of particular biological interest based on one specific set of assumptions concerning the times after detonations and the amounts of the radionuclides available. Abundances of nuclides one month after detonations less than 1000 curies per megaton are initially assumed to be insignificant, and "significance" as used here is related to this assumption. Each nuclide of significance is considered individually.

It is difficult, at least without making a special study, to set forth criteria for screening the nuclides for their contribution to hazards in such a way that the screening process is efficient and requires tabulating only a few physical, chemical or biological properties. The nuclides meeting the criterion of abundance are considered from the standpoint of type and energy of radiations, daughter products and biochemical or physiological processes. Biological considerations include possible effects of internal and external radiation, critical organ, degree of absorption of nuclides following inhalation or ingestion and extent of their elimination from the body.

Gross radioactive products from nuclear weapons may present internal hazards associated with inhalation and ingestion under these conditions on a short-term basis (15, 16). It is not intended, however, to discuss these short-term hazards or the long-term effects of acute doses of radiation in this problem. Of particular interest in the discussion of radionuclides from the standpoint of internal deposition are nuclides which are "bone seekers", having effects on some of the blood-forming organs as well as on bone. Nuclides which may affect other blood-forming organs are also of interest. These effects cause damage to the entire body because of the physiological nature and function of the blood. Other nuclides of particular biological interest are those whose general distribution in the body may produce genetic effects in addition to those sustained through chronic exposure to external radiation.

There is a limited amount of data available on the internal deposition of radionuclides in man, particularly bone-seekers following relatively heavy radioactive fallout (17). These data give some indication of potentially hazardous radionuclides although their actual effects are not well known.

As can be seen from the data of Appendices A and E a number of fission product radionuclides are obviously interesting from a biological standpoint and most of these have been considered so by others as mentioned above (2, 6, 20). These include many of the bone-seekers having abundances at one month and/or at one year of significant amounts. Others which are associated by decay and metabolic properties would also be included. Sr^{89} , Y^{91} , Zr^{95} - Nb^{95} , Ba^{140} - La^{140} , Ce^{143} - Pr^{143} , Ce^{144} - Pr^{144} and Nd^{147} - Pm^{147} would be potentially interesting bone-seeking nuclides from the intermediate range or tropospheric fallout point of view. I^{131} which is selectively taken up by the thyroid would also be potentially interesting from this point of view. Sr^{90} - Y^{90} and Cs^{137} - Ba^{137m} and possibly Ce^{144} and Pm^{147} , would be potentially interesting from the long-term or stratospheric fallout point of view. The gamma-emitting nuclides of potential interest which have been mentioned here also contribute most

of the external gamma radiation associated with intermediate and long-term fallout and may collectively be considered potentially hazardous from this standpoint.

It would not be expected that the noble gases would present serious biological problems even though some may be present in amounts of the same order of magnitude as the nuclides mentioned above. Since they are not actively metabolized, the internal concentrations of noble gases would be expected to be extremely low where fallout is considered. At extremely high concentrations in air, much higher than would normally be expected in fallout, external dosage consideration may be warranted (1) but will not be considered here.

Other fission products which initially appear to be of interest do not present serious problems. Mo^{99} - $\text{Tc}^{99\text{m}}$, Rb^{105} , Ag^{111} , $\text{Cd}^{115\text{m}}$, Te^{132} - I^{132} , and Pm^{149} , although present in significant quantities after one month would not be present in such quantities much longer (2 - 3 months) than this. Since they also have relatively short effective half-lives (less than three days) they would not present individually serious hazards except where their production rates were considerably high, as well as continuous. Ru^{103} , and Rh^{103} - Pd^{103} have relatively short effective half-lives and are present in relatively small amounts after one month, although greater than the assumed value of 1000 curies/MT. Although Sb^{125} and Eu^{155} were found in a few soil samples at Rongelap Atoll about three years after heavy fallout (21), the amounts present do not indicate any biological importance. All of the nuclides mentioned above in this paragraph are relatively poorly absorbed and retained in the body or critical organ, except for Te^{132} - I^{132} which is rapidly eliminated by radioactive decay, as are Ru^{106} - Rh^{106} , Sn^{123} , Sn^{125} - Sb^{125} , Sb^{127} - $\text{Te}^{127\text{m}}$ - Te^{127} , $\text{Te}^{129\text{m}}$ - Te^{129} , Ce^{141} , Sm^{151} , Eu^{155} and Eu^{156} . If the hazard to man involves the procession of these nuclides through the food chain, a further reduction of their potential hazards would be expected. As mentioned earlier, these nuclides may collectively present possible biological hazards, but it does not appear that they are of individual concern.

From the discussion above it may be concluded that the fission products listed below are potentially interesting from the standpoint of radioactive fallout, at least until further investigation indicates otherwise.

Sr ⁸⁹	Cs ¹³⁷ - Ba ^{137m}
Sr ⁹⁰ - Y ⁹⁰	Ba ¹⁴⁰ - La ¹⁴⁰
Y ⁹¹	Ce ¹⁴³ - Pr ¹⁴³
Zr ⁹⁵ - Nb ⁹⁵	Ce ¹⁴⁴ - Pr ¹⁴⁴
I ¹³¹	Nd ¹⁴⁷ - Pm ¹⁴⁷

Although isotopes of unknown origin are not considered in detail in this report, it may be assumed that isotopes of Co, Zn, Fe and Mn are produced in significant amounts since measurable amounts have been found in fallout. Mn⁵⁴ is poorly absorbed and quickly eliminated from the body which reduces its biological importance so that it does not appear of particular interest. Since iron is readily absorbed and has a relatively long biological half-life, Fe⁵⁵ and Fe⁵⁹ are probably of interest. The isotopes of cobalt (Co⁵⁷, Co⁵⁸ and Co⁶⁰) appear to be of interest. Iron and cobalt are also involved in the blood-forming organs. Because of its long effective half-life, high-energy alpha emission, and its bone-seeking properties Pu²³⁹ is of potential biological interest.

C¹⁴ appears to be the only nuclide produced in sufficient quantities in air to be of interest. The primary interest in this nuclide is based on its possible genetic effects (see 22). Its incorporation and mixing in many phases of the biosphere insures its availability to biological systems.

It may be seen from the data of Appendix C that P³², Ca⁴⁵, Fe⁵⁵ and Fe⁵⁹, produced in soils, are present after one month in apparently significant amounts, although the significance of P³² is probably limited to potential intermediate or short-term biological hazards. Since the Fe isotopes may be produced in addition to that in weapons materials the total amounts appear to be significant. The metabolic properties of all of these isotopes, their long half-lives and abundances indicate a potential interest from a biological standpoint.

It appears that none of the radionuclides produced in sea water are present to any great extent after one month. All of the nuclides considered are either relatively short-lived or produced at very low yields.

Because of the selective accumulation (9 - 12) of some nuclides by many marine biological systems, some nuclides may be considered of interest since they may become available to man through food chains. Some effects may be found on some marine organisms also. The accumulation of certain radionuclides by some organisms is probably the result of formation of nuclides as fission products and from weapons materials together

with the small amounts produced in sea water. From the estimates made here it does not appear likely that particular sea water nuclides, except possibly S^{35} and Zn^{65} , are of biological interest, although when considered collectively a great deal of radioactivity may be accumulated by biological systems in the sea. Zn^{65} appears to be a potential hazard since it is accumulated in some marine organisms which may be used for food by man (23, 24). Sea water is not known to be the only source of this nuclide. The estimates here indicate less than 1 curie of Zn^{65} /MT is produced in sea water.

DISCUSSION AND SUMMARY

Estimates have been made of the abundances of potential radionuclides which may be found following nuclear detonations. In many cases the estimates have been based on little data and are necessarily crude. An attempt has been made to review the nuclear and decay properties of potential nuclides. These data may be useful in further studies of fallout from nuclear detonations.

Based on estimates of abundances and nuclear, physical, and metabolic properties an attempt has been made to determine, for a specific set of assumptions, which radionuclides are of potential biological interest. Many nuclides of interest from the standpoint of internal radiation will also contribute greatly to the chronic external radiations present in the environment from fallout. Obviously, the potential importance of each nuclide depends greatly on many factors. Some of these are: rate of testing; fission to fusion ratio; detonation characteristics, such as height or depth of burst, over sea or land; type of soils involved; neutron fluxes; weapon constituents; and biological factors, including the chemical and physical form of material and its subsequent procession to man, and the effects of each radionuclide on the pertinent human tissues. Because of these many variables and the lack of specific evidence, the evaluations attempted here merely indicate nuclides of biological interest. Others cannot be excluded by such evaluations.

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APPENDIX A - FISSION PRODUCT DATA

I. Decay Data

The following nuclear data for fission products have been extracted from references 3, 4, and 5. Yields are given for 10000 fissions. Estimated half lives (T) are indicated by *. The letter "m" added to mass numbers merely indicates different energy levels of nuclides of the same mass number, and no attempt is made to distinguish the higher energy levels. The data used here are primarily that of the Glendenin, et al, estimate, but where indicated, isotopes are included where shown, only from Present's estimate. Nuclides are also included which are not given in reference 1 so that complete decay schemes and more recent information are included herein. Unless otherwise indicated decay is β decay.

1. Nickel - At. No. 28

2. Copper - At. No. 29

2. Copper (continued)

e. Cu^{76} - yield 0.0389. $T = 2\text{s}^*$

f. Cu^{77} - yield 0.053. $T = 1.5\text{s}^*$

3. Zinc - At. No. 30

a. Zn^{72} - yield 0.000360. $T_{1/2} = 49\text{h}$. (see Ni^{72} for decay data) (β , ~95% ~0.3 Mev, 5% 1.6 Mev)

b. Zn^{73} - yield 0.00318. $T = 45\text{s}^*$. (see Ni^{73} for decay data)

c. Zn^{74} - yield 0.0102. $T = 4.5\text{m}^*$. (see Ni^{74} for decay data)

d. Zn^{75} - yield 0.0436. $T = 9.5\text{s}^*$. (see Cu^{75} for decay data)

e. Zn^{76} - yield 0.0966. $T = 8\text{s}^*$. (see Cu^{76} for decay data)

f. Zn^{77} - yield 0.219. $T = 3.5\text{s}^*$. (see Cu^{77} for decay data)

g. Zn^{78} - yield 0.423. $T = 2.5\text{s}^*$.

h. Zn^{79} - yield 0.64. $T = 1.5\text{s}^*$.

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- $$\text{Zn}^{80} \xrightarrow{1.5s^*} \text{Ga}^{80} \xrightarrow{3s^*} \text{Ge}^{80} \xrightarrow{25s^*} \text{As}^{80} \xrightarrow{2m^*} \text{Se}^{80} \text{ (stable)}$$

a. Ga^{72} - yield 0.000022. $T = 14.3\text{h}$

(see Ni⁷² for decay data) (β , 42% 0.64 Mev, 31% 0.96 Mev, 10% 1.51 Mev, 17% (2 others); γ , many).

- c. Ga^{74} - yield 0.00338. $T = 4.5\text{m*}$. (see Ni^{74} for decay data) (β ; γ , 0.58, 2.3, 2.6 Mev)

- d. Ga^{75} - yield 0.0259. $T = 70\text{s}^*$. (see Cu^{75} for decay data)

- e. Ga^{76} - yield 0.0789. $T = 30\text{s}^*$. (see Cu^{76} for decay data)

- f. Ga^{77} - yield 0.245. $T = 15\text{s}^*$. (see Cu^{77} for decay data)

- g. Ga^{78} - yield 0.654. $T = 8\text{s}^*$. (see Zn^{78} for decay data)

- h. Ga^{79} - yield 1.6. $T = 4.5\text{s}^*$. (see Zn^{79} for decay data)

- i. Ga^{80} - yield 2.47. . T = 3s*. (see Zn^{80} for decay data)

- j. Ga^{81} - yield 4.23. T = 26*.

4. Gallium (continued)

k. Ga^{82} - yield 3.84. $T = 1.5\text{s}^*$.

5. Germanium - At. No. 32

a. $\text{Ge}^{72\text{m}}$ - yield 0 - decay of Ga^{72} to Ge^{72} . $T = 0.3\mu\text{s}$. (see Ni^{72} for decay)(IT; γ , 0.68 Mev)

b. $\text{Ge}^{73\text{m}}$ - yield 0 - decay of Ga^{73} to Ge^{73} . $T = 0.53\text{s}$. (see Ni^{73} for decay)(IT; γ , 0.0539, 0.0135 Mev)

c. Ge^{75} - yield 0.0023. $T = 82\text{m}$. (see Cu^{75} for decay). (β , 85% 1.19 Mev, 11% 0.92 Mev, 3 others; γ 0.264, 0.199 Mev, 4 others)

d. $\text{Ge}^{77\text{m}}$ - yield 0.040. $T = 59\text{s}$. (see Cu^{77} for decay). (β , 2.8 Mev; γ , 0.215 Mev, IT, γ 0.159 Mev)

e. Ge^{77} - yield 0.041. $T = 12\text{h}$. (see Cu^{77} for decay). (β , 42% 2.2 Mev, 35% 1.38 Mev, 3 others; γ , 0.26, 0.56 Mev, 22 others)

f. Ge^{78} - yield 0.389. $T = 126\text{m}$. (see Zn^{78} for decay). (β , 0.9 Mev, γ)

g. Ge^{79} - yield 1.3. $T = 25\text{s}^*$. (see Zn^{79} for decay). (β)

h. Ge^{80} - yield 3.02. $T = 25\text{s}^*$. (see Zn^{80} for decay)

i. Ge^{81} - yield 6.54. $T = 7\text{s}^*$. (see Ga^{81} for decay)

j. Ge^{82} - yield 11.45. $T = 5\text{s}^*$. (see Ga^{82} for decay)

k. Ge^{83} - yield 18.6. $T = 2\text{s}^*$.

5. Germanium

k. Ge^{83} (continued)

l. Ge^{84} - yield 16.2. $T = 1.5s^*$.

m. Ge^{85} - yield 14.4. $T = 1s^*$.

6. Arsenic - At. No. 33

a. As^{77} - yield 0.002. $T = 40h$. (see Cu^{77} for decay). (β , 98% 0.68 Mev, 2% 2 others; γ , 0.245, 0.52, 0.086, 0.160 Mev).

b. As^{78} - yield 0.035. $T = 90m$. (see Zn^{78} for decay). (β , ~70% 4.1 Mev, 30% 1.4 Mev; γ , 0.27 Mev)

c. As^{79} - yield 0.26. $T = 9m$. (see Zn^{79} for decay). (β , 2.3 Mev; no γ).

d. As^{80} - yield 1.19. $T = 2m^*$. (see Zn^{80} for decay). (β).

e. As^{81} - yield 3.89. $T = 50s^*$. (see Ga^{81} for decay). (β).

f. As^{82} - yield 10.2. $T = 18s^*$. (see Ga^{82} for decay). (β).

6. Arsenic (continued)

- g. As^{83} - yield 22. $T = 7s^*$. (see Ge^{83} for decay).
- h. As^{84} - yield 34.6. $T = 4s^*$. (see Ge^{84} for decay).
- i. As^{85} - yield 50.8. $T = 2.5s^*$. (see Ge^{85} for decay).
- j. As^{86} - yield 56.4. $T = 2s^*$. $\text{As}^{86} \xrightarrow{2s^*} \text{Se}^{86} \xrightarrow{7s^*} \text{Br}^{86} \xrightarrow{32s^*} \text{Kr}^{86} \text{ (stable)}$
- k. As^{87} - yield 38.4. $T = 1.5s^*$. $\text{As}^{87} \xrightarrow{1.5s^*} \text{Se}^{87} \xrightarrow{3s^*} \text{Br}^{87} \xrightarrow{98\%} \text{Kr}^{87} \xrightarrow{78m} \text{Rb}^{87} \xrightarrow{5 \times 10^{10}y} \text{Sr}^{87} \text{ (stable)}$
 $\text{Br}^{87} \xrightarrow{55.6s} \text{Kr}^{87} \xrightarrow{2\%} \text{Kr}^{87m} \xrightarrow{n, \text{Inst.}} \text{Kr}^{86} \text{ (stable)}$

7. Selenium - At. No. 34.

- a. Se^{77m} - yield - 2% decay of As^{77} . $T = 17.5s$. (IT; γ , 0.162 Mev).
- b. Se^{79m} - yield - decay of As^{79} . $T = 3.9m$. (IT; γ , 0.096 Mev).
- c. Se^{79} - yield - decay of Se^{79m} . $T = \text{or} < 6 \times 10^4y$. (β , 0.160 Mev; no γ).
- d. Se^{81m} - yield 0.18. $T = 57m$. (see Ga^{81} for decay) (IT; γ , 0.103 Mev).
- e. Se^{81} - yield 0.17. $T = 13.6m$. (see Ga^{81} for decay) (β , 1.38 Mev; no γ).
- f. Se^{83m} - yield 5. $T = 67s$. (see Ge^{83} for decay) (IT; β , 3.4 Mev; γ).
- g. Se^{83} - yield 5. $T = 25m$. (see Ge^{83} for decay) (β , 1.5 Mev; γ , 0.176, 0.37, 0.95 Mev).
- h. Se^{84} - yield 25.4. $T = 2m$. (see Ge^{84} for decay) (β).
- i. Se^{85} - yield 50.8. $T = 2s^*$. (see Ge^{85} for decay).
- j. Se^{86} - yield 87.2. $T = 7s^*$. (see As^{86} for decay).
- k. Se^{87} - yield 115. $T = 3s^*$. (see As^{87} for decay).

8. Bromine (continued)

1. Br^{91} - yield 92. $T = 2s^*$.

j. Br^{92} - yield 39. $T = 1.5s^*$. $\text{Br}^{92} \xrightarrow{1.5s^*} \text{Kr}^{92} \xrightarrow{3s} \text{Rb}^{92} \xrightarrow{17s^*} \text{Sr}^{92} \xrightarrow{2.7h} \text{Y}^{92} \xrightarrow{3.5h} \text{Zr}^{92} \text{ (stable)}$

9. Krypton - At. No. 36.

a. Kr^{83m} - yield 0. $T = 108m$. (see Ge^{83} for decay) (IT; γ , 0.00093, 0.0322 Mev).

b. Kr^{85m} - yield 0. $T = 4.36h$. (see Ge^{85} for decay) (23% IT; 77% β , 0.825 Mev; γ , 0.150, 0.305 Mev).

c. Kr^{85} - yield 0. $T = 9.4y$. (see Ge^{85} for decay) (β ; 99% 0.67 Mev, 0.6% 0.15 Mev; no γ).

d. Kr^{87m} - yield - 2% neutron decay of Br^{87} to Kr^{86} . $T = \text{inst.}$ (0.3 Mev neutron).

e. Kr^{87} - yield 25. $T = 78m$. (see As^{87} for decay) (β , ~65% 3.6 Mev, ~35% 2 others; γ , 0.40, 2.6, 0.85 Mev, 2 others?).

f. Kr^{88} - yield 79. $T = 2.77h$. (see Se^{88} , Se^{89} for decay) (β , 68% 0.52 Mev, 20% 2.8 Mev, 12% 0.9 Mev; γ , 0.028, 0.191, 2.4, 0.845 Mev and others).

g. Kr^{89} - yield 158. $T = 3.16m$. (see Se^{89} for decay) (β , <65% 4.0 Mev, ~35% ~2 Mev, others?; γ).

h. Kr^{90} - yield 220. $T = 33s$. (see Br^{90} for decay) (β , 3.2 Mev, others; γ).

i. Kr^{91} - yield 225. $T = 9.8s$. (see Br^{91} for decay) (β , ~3.6 Mev; γ).

9. Krypton (continued)

j. Kr^{92} - yield 199. $T = 3\text{s}$. (see Br^{92} for decay) (β).

k. Kr^{93} - yield 121. $T = 2\text{s}$. (β).

l. Kr^{94} - yield 42. $T = 1.4\text{s}$. (β).

10. Rubidium - At. No. 37

a. $\text{Rb}^{85\text{m}}$ - yield 0 - decay of $\text{Kr}^{85\text{m}}$ to Rb^{85} . $T = 0.9\mu\text{s}$. (see Ge^{85} for decay) (IT; γ , 0.513 Mev).

b. Rb^{87} - yield 0 - decay of Kr^{87} to Sr^{87} (naturally radioactive). (see As^{87} for decay) (β , 0.215 Mev; no γ).

c. Rb^{88} - yield 5. $T = 17.8\text{m}$. (see Se^{88} , Se^{89} for decay) (β , ~ 75% 5.3 Mev, ~ 15% 3.6 Mev, ~ 10% 2.5 Mev; γ , 1.85, 0.91, 2.7 Mev, 7 others).

d. Rb^{89} - yield 31. $T = 15.4\text{m}$. (see Se^{89} for decay) (β , ~ 7% 3.92 Mev, 5% 2.87 Mev, 88% 5 others; γ , 1.05, 1.26, 0.66 Mev, 5 others).

e. Rb^{90} - yield 100. $T = 2.7\text{m}$. (see Br^{90} for decay) (β , 5.7 Mev, 5 others; γ).

f. $\text{Rb}^{91\text{m}}$ - yield 92. $T = 14\text{m}$. (see Br^{91} for decay) (β , 3.0 Mev, others; γ).

g. Rb^{91} - yield 93. $T = 100\text{s}$. (see Br^{91} for decay) (β , 4.6 Mev, others; γ).

h. Rb^{92} - yield 243. $T = 17\text{s}^*$. (see Br^{92} for decay) (β).

10. Rubidium (continued)

- i. Rb^{93} - yield 259. $T = 7\text{s}^*$. (see Kr^{93} for decay) (β).
 j. Rb^{94} - yield 213. $T = 3\text{s}^*$. (see Kr^{94} for decay) (β),
 k. Rb^{95} - yield 150. $T = 2\text{s}^*$.

11. Strontium - At. No. 38.

- a. Sr^{89} - yield 0. $T = 53\text{d}$. (see Se^{89} for decay) (β , 1.463 Mev; $\sim 0.01\%$ γ , 0.95 Mev).
 b. Sr^{90} - yield 4. $T = 28\text{y}$ (19.9y, ref. 3). (see Br^{90} for decay) (β , 0.61 Mev; no γ).
 c. Sr^{91} - yield 34. $T = 9.7\text{h}$. (see Br^{91} for decay) (β , 33% 1.09 Mev, 29% 1.36 Mev, 27% 2.665 Mev, 7% 0.62 Mev, 4% 2.03 Mev; γ , 0.645, 0.748, 1.025, 1.413 Mev).
 d. Sr^{92} - yield 96. $T = 2.7\text{h}$. (see Br^{92} for decay) (β , 90% 0.55 Mev, 10% 1.50 Mev; γ , 1.38, 0.44 Mev).
 e. Sr^{93} - yield 191. $T = 7\text{m}$. (see Kr^{93} for decay) (β).
 f. Sr^{94} - yield 260. $T = 2\text{m}$. (see Kr^{94} for decay) (β).
 g. Sr^{95} - yield 274. $T = 6\text{s}^*$. (see Rb^{95} for decay) (β).
 h. Sr^{96} - yield 234. $T = 2.5\text{s}^*$. (see Rb^{96} for decay).
 i. Sr^{97} - yield 180. $T = 1.5\text{s}^*$. (β). $\text{Sr}^{97} \xrightarrow{1.5\text{s}^*} \text{Y}^{97} \xrightarrow{5\text{s}^*} \text{Zr}^{97} \xrightarrow{17\text{h}} \text{Nb}^{97\text{m}} \xrightarrow{\text{IT}} \text{Nb}^{97} \xrightarrow{60\text{s}} \text{Mo}^{97} \text{ (stable)}$

11. Strontium (continued)

j. Sr^{98} - yield 68. $T = 1s^*$. $\text{Sr}^{98} \xrightarrow{1s^*} \text{Y}^{98} \xrightarrow{2.5s^*} \text{Zr}^{98} \xrightarrow{15s^*} \text{Nb}^{98} \xrightarrow{30m} \text{Mo}^{98} \text{ (stable)}$

k. Sr^{99} - yield < 5% of chain; Present's est. yield 44. $T = 1s^*$.

12. Yttrium - At. No. 39.

a. Y^{89m} - yield 0 - decay of Sr^{89} to Y^{89} . $T = 16.1s$. (IT; γ , 0.915 Mev).

b. Y^{90} - yield 0. $T = 61h$. (see Br^{90} for decay) (β , 2.24 Mev; no γ).

c. Y^{91m} - yield 0. $T = 51m$. (see Br^{91} for decay) (IT; γ , 0.551 Mev).

d. Y^{91} - yield 0. $T = 57d$. (see Br^{91} for decay) (β , 99.8% 1.55 Mev, 0.2% 0.36 Mev; γ , 0.2% 1.19 Mev).

e. Y^{92} - yield 3. $T = 3.5h$. (see Br^{92} for decay) (β , 1.3, 2.7, 3.6 Mev, other?; γ , 0.94, 0.48, 0.21, 1.45, 2.4, 1.9 Mev).

f. Y^{93} - yield 29. $T = 10h$. (see Kr^{93} for decay) (β , 85% 3.1 Mev; γ , 0.7 Mev, others?).

g. Y^{94} - yield 102. $T = 16.5m$. (see Kr^{94} for decay) (β , 5.4 Mev; γ , 1.4 Mev)

h. Y^{95} - yield 183. $T = 1m^*$. (see Rb^{95} for decay) (β).

i. Y^{96} - yield 262. $T = 10s^*$. (see Rb^{96} for decay).

j. Y^{97} - yield 279. $T = 5s^*$. (see Sr^{97} for decay) (β).

k. Y^{98} - yield 242. $T = 2.5s^*$. (see Sr^{98} for decay).

12. Yttrium (continued)

- l. Y^{99} - yield 169. $T = 1.5s^*$. (see Sr^{99} for decay).
 m. Y^{100} - yield 78. $T = 1.5s^*$. $Y^{100} \xrightarrow{1.5s^*} Zr^{100} \xrightarrow{3.5s^*} Nb^{100} \xrightarrow{27s} Mo^{100}$ (stable)
 n. Y^{101} - yield < 5% of chain, Present's est. yield 82. $T = 1s^*$.

13. Zirconium - At. No. 40.

- a. Zr^{93} - yield 0 - decay of Y^{93} to Nb^{93} . $T = 1.1 \times 10^6 y$. (β , 3.1 Mev; γ , 0.7 Mev).
 b. Zr^{95} - yield 22. $T = 65d$. (see Rb^{95} for decay) (β , 54% 0.36 Mev, 43% 0.400 Mev, ~ 2% 0.88 Mev, ~ 1% 2 others; γ , 54% 0.754 Mev, 43% 0.722 Mev).
 c. Zr^{97} - yield 165. $T = 17h$. (see Sr^{97} for decay) (β , 1.91 Mev; γ , 1.6 Mev).
 d. Zr^{98} - yield 242. $T = 15s^*$. (see Sr^{98} for decay).
 e. Zr^{99} - yield 262. $T = 5.5s^*$. (see Sr^{99} for decay) (β).
 f. Zr^{100} - yield 233. $T = 3.5s^*$. (see Y^{100} for decay).
 g. Zr^{101} - yield 179. $T = 2.5s^*$. (see Y^{101} for decay).
 h. Zr^{102} - yield 85. $T = 2s^*$. $Zr^{102} \xrightarrow{2s^*} Nb^{102} \xrightarrow{7s^*} Mo^{102} \xrightarrow{11m} Tc^{102} \xrightarrow{100s^*} Ru^{102}$ (stable)
 i. Zr^{103} - yield 37. $T = 1.5s^*$.

14. Niobium - At. No. 41.

- a. Nb^{93m} - yield 0, decay of Y⁹³ to Nb⁹³. T = ~ 10y. (see Kr⁹³ for decay) (IT; γ, 0.030 Mev).
- b. Nb^{95m} - yield 0. T = 90h. (see Rb⁹⁵ for decay) (IT; γ, 0.235 Mev).
- c. Nb⁹⁵ - yield 0. T = 35d. (see Rb⁹⁵ for decay) (β, 99% 0.160 Mev 1% 0.93 Mev; γ, 0.764 Mev).
- d. Nb^{97m} - yield 7. T = 60s. (see Sr⁹⁷ for decay) (IT; γ, 0.747 Mev).
- e. Nb⁹⁷ - yield 7. T = 74m. (see Sr⁹⁷ for decay) (β, 1.267 Mev; γ, 0.665 Mev).
- f. Nb⁹⁸ - yield 68. T = 30m. (see Sr⁹⁸ for decay) (β).
- g. Nb⁹⁹ - yield 155. T = 2.5m. (see Sr⁹⁹ for decay) (β, 3.2 Mev).
- h. Nb¹⁰⁰ - yield 208. T = 27s*. (see Y¹⁰⁰ for decay).
- i. Nb¹⁰¹ - yield 212. T = 11s*. (see Y¹⁰¹ for decay).
- j. Nb¹⁰² - yield 181. T = 7s*. (see Zr¹⁰² for decay).
- k. Nb¹⁰³ - yield 133. T = 4s*. (see Zr¹⁰³ for decay).
- l. Nb¹⁰⁴ - yield 68. T = 3s*. Nb¹⁰⁴ $\xrightarrow{3s^*}$ Mo¹⁰⁴ $\xrightarrow{18s^*}$ Tc¹⁰⁴ $\xrightarrow{30s^*}$ Ru¹⁰⁴ (stable)
- m. Nb¹⁰⁵ - yield 16.9. T = 2s*.
- Nb¹⁰⁵ $\xrightarrow{2s^*}$ Mo¹⁰⁵ $\xrightarrow{6s^*}$ Tc¹⁰⁵ $\xrightarrow{15s^*}$ Ru¹⁰⁵ $\xrightarrow{4.5h}$ Rh^{105m}
IT ↓ 45s
Rh¹⁰⁵ $\xrightarrow{36.5h}$ Pd¹⁰⁵ (stable)
- n. Nb¹⁰⁶ - yield 4.4. T = 1.5s.
- Nb¹⁰⁶ $\xrightarrow{1.5s^*}$ Mo¹⁰⁶ $\xrightarrow{4s^*}$ Tc¹⁰⁶ $\xrightarrow{9s^*}$ Ru¹⁰⁶ $\xrightarrow{1y}$ Rh¹⁰⁶ $\xrightarrow{30s}$ Pd¹⁰⁶ (stable)

14. Niobium (continued)

- a. Nb^{107} - yield < 5% of chain, Present's est. yield 2.0. $T = 1s^*$.

15. Molybdenum - At. No. 42.

- a. Mo^{99} - yield 14. $T = 68h$. (see Sr^{99} for decay) (β , ~ 87% 1.23 Mev, ~ 13% 0.45 Mev, other? γ , 0.040, 0.140, 0.181, 0.37, 0.741, 0.780, 0.845 Mev).

- b. Mo^{101} - yield 96. $T = 14.6m$. (see Y^{101} for decay) (β , 70% 1.2 Mev, 30% 2.2 Mev; γ , 0.192, 0.96 Mev).

- c. Mo^{102} - yield 133. $T = 11m$. (see Zr^{102} for decay) (β , 1.0 Mev).

- d. Mo^{103} - yield 133. $T = 25s^*$. (see Zr^{103} for decay).

- e. Mo^{104} - yield 91. $T = 18s^*$. (see Nb^{104} for decay).

- f. Mo^{105} - yield 42. $T = 6s^*$. (see Nb^{105} for decay) (β).

- g. Mo^{106} - yield 18.3. $T = 4s^*$. (see Nb^{106} for decay).

- h. Mo^{107} - yield 6.52. $T = 2.5s^*$. (see Nb^{107} for decay).

- i. Mo^{108} - yield 1.12. $T = 2s^*$. $\text{Mo}^{108} \xrightarrow{2s^*} \text{Tc}^{108} \xrightarrow{3.5s^*} \text{Ru}^{108} \xrightarrow{6m} \text{Rh}^{108} \xrightarrow{80s} \text{Pd}^{108} \text{ (stable)}$

- j. Mo^{109} - yield 0.25. $T = 1.5s^*$. $\text{Mo}^{109} \xrightarrow{1.5s^*} \text{Tc}^{109} \xrightarrow{2.5s^*} \text{Ru}^{109} \xrightarrow{16s^*} \text{Rh}^{109} \xrightarrow{40s^*} \text{Pd}^{109} \xrightarrow{13h} \text{Ag}^{109m, IT} \xrightarrow{} \text{Ag}^{109} \text{ (stable)}$

- k. Mo^{110} - yield < 5% of chain, Present's est. yield 0.148. $T = 1s^*$.

16. Technetium - At. No. 43.

- a. Tc^{99m} - yield 0. T = 5.9h. (see Sr⁹⁹ for decay) (IT; β , 0.03%; γ , 99% 0.140 Mev, 1% 0.142 Mev).
- b. Tc⁹⁹ - yield 0, decay of Tc^{99m} to Ru⁹⁹. T = 2x10⁵y. (β , 0.290 Mev; no γ).
- c. Tc¹⁰¹ - yield 3. T = 15m. (see Y¹⁰¹ for decay) (β , 1.32, 1.07, others; γ , 0.307, 0.548, 0.130, 0.94, others).
- d. Tc¹⁰² - yield 20. T = 100s* (4.5m ref. 10). (see Zr¹⁰² for decay) (β , 4 Mev; γ 's).
- e. Tc¹⁰³ - yield 37. T = 60s*. (see Zr¹⁰³ for decay).
- f. Tc¹⁰⁴ - yield 47. T = 30s* (18m ref. 10). (see Nb¹⁰⁴ for decay) (β).
- g. Tc¹⁰⁵ - yield 34.3. T = 15s*. (see Nb¹⁰⁵ for decay) (β).
- h. Tc¹⁰⁶ - yield 20.5. T = 9s*. (see Nb¹⁰⁶ for decay).
- i. Tc¹⁰⁷ - yield 8.7. T = 6s*. (see Nb¹⁰⁷ for decay) (β).
- j. Tc¹⁰⁸ - yield 2.77. T = 3.5s*. (see Mo¹⁰⁸ for decay).
- k. Tc¹⁰⁹ - yield 1.02. T = 2.5s*. (see Mo¹⁰⁹ for decay).
- l. Tc¹¹⁰ - yield 0.652. T = 2s*. (see Mo¹¹⁰ for decay).
- m. Tc¹¹¹ - yield 0.270. T = 1.5s*.

- n. Tc¹¹² - yield 0.125. T = 1.5s*.

18. Rhodium - At. No. 45.

- a. Rh^{103m} - yield 0. T = 57m. (see Zr¹⁰³ for decay) (IT; γ , 0.040 Mev).
- b. Rh^{105m} - yield 0. T = 45s. (see Nb¹⁰⁵ for decay) (IT; γ , 0.130 Mev).
- c. Rh¹⁰⁵ - yield 0. T = 36.5h. (see Nb¹⁰⁵ for decay) (β , 1.15 Mev; γ , 0.73 Mev).
- d. Rh¹⁰⁶ - yield 0. T = 30s. (see Nb¹⁰⁶ for decay) (β , 68% 3.53 Mev, 32% 3 others; γ , 0.153, 0.624 Mev, 8-9 others).
- e. Rh¹⁰⁷ - yield 27. T = 26m. (see Nb¹⁰⁷ for decay) (β , 1.15, ~ 2 Mev; γ , 0.32, 0.40, 0.58, 0.68, others).
- f. Rh¹⁰⁸ - yield 0.45. T = 80s. (see Mo¹⁰⁸ for decay) (β , ~ 4.5 Mev; γ).
- g. Rh¹⁰⁹ - yield 0.38. T = 40s*. (see Mo¹⁰⁹ for decay) (β).
- h. Rh¹¹⁰ - yield 0.450. T = 20s*. (see Mo¹¹⁰ for decay).
- i. Rh¹¹¹ - yield 0.549. T = 12s*. (see Tc¹¹¹ for decay).
- j. Rh¹¹² - yield 0.573. T = 7s*. (see Tc¹¹² for decay).
- k. Rh¹¹³ - yield 0.609. T = 4s*. (see Ru¹¹³ for decay).
- l. Rh¹¹⁴ - yield 0.562. T = 3s*. (see Ru¹¹⁴ for decay).
- m. Rh¹¹⁵ - yield 0.429. T = 2.5s*. (see Ru¹¹⁵ for decay).
- n. Rh¹¹⁶ - yield 0.350. T = 2s*. $\text{Rh}^{116} \xrightarrow{2s*} \text{Pd}^{116} \xrightarrow{10s*} \text{Ag}^{116} \xrightarrow{2m*} \text{Cd}^{116} \text{ (stable)}$
- o. Rh¹¹⁷ - yield 0.239. T = 1.5s*.

18. Rhodium (continued)

p. Rh^{118} - yield 0.151. $T = 1.5\text{s}^*$.

q. Rh^{119} - yield 0.082. $T = 1.5\text{s}^*$.

19. Palladium - At. No. 46.

a. Pd^{107} - yield 0, decay of Rh^{107} to Ag^{107} . $T = 7.5 \times 10^4\text{y}$. (see Nb^{107} for decay) (β , 0.04 Mev).

b. Pd^{109} - yield 0. $T = 13\text{h}$. (see Mo^{109} or decay) (β , 0.99 Mev; no γ)

c. Pd^{112} - yield 0.109. $T = 26\text{m}$. (see Tc^{112} for decay) (β , 2.13 Mev; γ , 0.38, 0.56, 0.65, 0.73 Mev).

d. Pd^{112} - yield 0.189. $T = 21\text{h}$. (see Tc^{112} for decay) (β , 0.28 Mev; γ , 0.0185 Mev).

e. Pd^{113} - yield 0.315. $T = 55\text{s}^*$. (see Ru^{113} for decay).

f. Pd^{114} - yield 0.413. $T = 60\text{s}^*$. (see Ru^{114} for decay).

g. Pd^{115} - yield 0.429. $T = 13\text{s}^*$. (see Ru^{115} for decay).

h. Pd^{116} - yield 0.475. $T = 10\text{s}^*$. (see Rh^{116} for decay).

i. Pd^{117} - yield 0.435. $T = 5\text{s}^*$. (see Rh^{117} for decay).

j. Pd^{118} - yield 0.450. $T = 4.5\text{s}^*$. (see Rh^{118} for decay).

k. Pd^{119} - yield 0.082. $T = 3\text{s}^*$. (see Rh^{119} for decay).

l. Pd^{120} - yield 0.338. $T = 2\text{s}^*$. $\text{Pd}^{120} \xrightarrow{2\text{s}^*} \text{Ag}^{120} \xrightarrow{6\text{s}^*} \text{Cd}^{120} \xrightarrow{12\text{m}^*} \text{In}^{120} \xrightarrow{2\text{m}^*} \text{Sn}^{120} \text{ (stable)}$

m. Pd^{121} - yield 0.220. $T = 1.5\text{s}^*$. $\text{Pd}^{121} \xrightarrow{1.5\text{s}^*} \text{Ag}^{121} \xrightarrow{4\text{s}^*} \text{Cd}^{121} \xrightarrow{25\text{s}^*} \text{In}^{121} \xrightarrow{75\text{s}^*} \text{Sn}^{121} \xrightarrow{27\text{n}} \text{Sb}^{121} \text{ (stable)}$

n. Pd^{122} - yield 0.134. $T = 1.5\text{s}^*$. $\text{Pd}^{122} \xrightarrow{1.5\text{s}^*} \text{Ag}^{122} \xrightarrow{3\text{s}^*} \text{Cd}^{122} \xrightarrow{40\text{s}^*} \text{In}^{122} \xrightarrow{45\text{s}^*} \text{Sn}^{122} \text{ (stable)}$

20. Silver - At. No. 47.

- a. Ag^{109m} - yield 0. T = 39s. (see Mo¹⁰⁹ for decay) (IT; γ , 0.0875 Mev).
 b. Ag^{111m} - yield 0. T = 76s. Decay of Pd¹¹¹ to Ag^{111m}. (IT; γ , 0.060 Mev).
 c. Ag¹¹¹ - yield 0. T = 7.6d. (see Tc¹¹¹ for decay) (β , 91% 1.04 Mev, 9% 2 others; γ , 0.34 Mev).
 d. Ag¹¹² - yield 0.003. T = 3.2h. (see Tc¹¹² for decay) (β , ~40% ~3.6 Mev, ~25% 4.1 Mev, ~35% others; γ , 0.62, 1.39, 1.62, 2.11 Mev, 4 others).

e. Ag¹¹³ - yield 0.020. T = 5.3h. (see Ru¹¹³ for decay) (β , 2.1 Mev; no γ).

f. Ag¹¹⁴ - yield 0.062. T = 2m. (see Ru¹¹⁴ for decay) (β).

g. Ag¹¹⁵ - yield 0.121. T = 20m. (see Ru¹¹⁵ for decay) (β , ~3 Mev; no γ).

h. Ag¹¹⁶ - yield 0.215. T = 2m*. (see Rh¹¹⁶ for decay).

i. Ag¹¹⁷ - yield 0.290. T = 50s*. (see Rh¹¹⁷ for decay).

j. Ag¹¹⁸ - yield 0.402. T = 25s*. (see Rh¹¹⁸ for decay).

k. Ag¹¹⁹ - yield 0.504. T = 17s*. (see Rh¹¹⁹ for decay).

l. Ag¹²⁰ - yield 0.522. T = Gs*. (see Pd¹²⁰ for decay).

m. Ag¹²¹ - yield 0.546. T = 4s*. (see Pd¹²¹ for decay).

n. Ag¹²² - yield 0.548. T = 3s*. (see Pd¹²² for decay).

o. Ag¹²³ - yield 0.554. T = 2.5s*. Ag¹²³ $\xrightarrow{2.5s^*}$ Cd¹²³ $\xrightarrow{9s^*}$ In¹²³ $\xrightarrow{30s^*}$ Sn¹²³ $\xrightarrow{130d}$ Sb¹²³ (stable)

p. Ag¹²⁴ - yield 0.404. T = 2s*. Ag¹²⁴ $\xrightarrow{2s^*}$ Cd¹²⁴ $\xrightarrow{10s^*}$ In¹²⁴ $\xrightarrow{20s^*}$ Sn¹²⁴ (stable)

q. Ag¹²⁵ - yield 0.223. T = 2s*. Ag¹²⁵ $\xrightarrow{2s^*}$ Cd¹²⁵ $\xrightarrow{5s^*}$ In¹²⁵ $\xrightarrow{15s^*}$ Sn¹²⁵ $\xrightarrow{10d}$ Sb¹²⁵ $\xrightarrow{2.7y, 83\%}$ Te^{125m} $\xrightarrow{IT, 58d}$ Te¹²⁵ (stable)
 Sb¹²⁵ $\xrightarrow{17\%}$ Te¹²⁵ (stable)

21. Cadmium - At. No. 48.

- a. Cd^{111m} - yield 0, decay of Ag¹¹¹ to Cd¹¹¹. T = 48.6m. (IT; γ , 0.148, 0.247 Mev)
- b. Cd^{115m} - yield 0. T = 42.6d. (see Ru¹¹⁵ for decay) (β , 97% 1.61 Mev, 3% others; γ , 0.94, 1.30, 0.48 Mev).
- c. Cd¹¹⁵ - yield 0. T = 2.33d. (see Ru¹¹⁵ for decay) (β , 63% 1.11 Mev, 37% 3 others; γ , 0.523, 0.49 Mev, 3 others).
- d. Cd^{117m} - yield 0.036. T = 2.72h. (see Rh¹¹⁷ for decay) (IT; β ; γ , 0.27, 2.0 Mev, 6 others).
- e. Cd¹¹⁷ - yield 0. T = 50m. Decay of Cd^{117m}. (see Rh¹¹⁷ for decay) (β , ~1.6, ~3.0 Mev; γ , ~1.2 Mev).
- f. Cd¹¹⁸ - yield 0.098. T = 10y*. (see Rh¹¹⁸ for decay) (β , ~4 Mev).
- g. Cd¹¹⁹ - yield 0.198. T = 3m*. (~10m ref. 10) (see Rh¹¹⁹ for decay).
- h. Cd¹²⁰ - yield 0.311. T = 12m*. (see Pd¹²⁰ for decay).
- i. Cd¹²¹ - yield 0.446. T = 25s*. (3.5m ref. 10). (see Pd¹²¹ for decay) (γ , 0.85 Mev).
- j. Cd¹²² - yield 0.614. T = 40s*. (see Pd¹²² for decay).
- k. Cd¹²³ - yield 0.740. T = 9s*. (see Ag¹²³ for decay).
- l. Cd¹²⁴ - yield 0.864. T = 10s*. (see Ag¹²⁴ for decay).
- m. Cd¹²⁵ - yield 0.913. T = 5s*. (see Ag¹²⁵ for decay).
- n. Cd¹²⁶ - yield 2.61. T = 3s*. Cd¹²⁶ $\xrightarrow{3s^*}$ In¹²⁶ $\xrightarrow{7s^*}$ Sn¹²⁶ $\xrightarrow{50m}$ Sb¹²⁶ $\xrightarrow{9h}$ Te¹²⁶ (stable)
- o. Cd¹²⁷ - yield 3.24. T = 1.5s*. Cd¹²⁷ $\xrightarrow{1.5s^*}$ In¹²⁷ $\xrightarrow{3s^*}$ Sn¹²⁷ $\xrightarrow{85m}$ Sb¹²⁷ $\xrightarrow{20.6\% \text{ } 9.3h}$ Te^{127m} $\xrightarrow{90d}$ I¹²⁷ (stable)
 Sb¹²⁷ $\xrightarrow{79.4\%}$ Te¹²⁷ $\xrightarrow{9.3h}$ I¹²⁷ (stable)
 Te^{127m} $\xrightarrow{IT \text{ } 98\%}$ Te¹²⁷

21. Cadmium (continued)

p. Cd^{128} - yield 4.6. $T = 1\text{s}^*$. $\text{Cd}^{128} \xrightarrow{1\text{s}^*} \text{In}^{128} \xrightarrow{2\text{s}^*} \text{Sn}^{128} \xrightarrow{10\text{s}^*} \text{Sb}^{128} \xrightarrow{1.1\text{h}^*} \text{Te}^{128}$ (stable)

22. Indium - At. No. 49.

- a. $\text{In}^{115\text{m}}$ - yield 0. $T = 4.53\text{h}$. (see Ru^{115} for decay) (95% IT; γ , 0.335 Mev; 5% β , 0.83 Mev).
- b. In^{115} - yield 0. $T = 6 \times 10^4\text{y}$. (found in nature) (see Ru^{115} for decay) (β , 0.50 Mev).
- c. $\text{In}^{117\text{m}}$ - yield 0. $T = 1.95\text{h}$. (see Rh^{117} for decay) (22% IT; γ , 0.311 Mev; 55% β , 1.77 Mev; 23% β , 1.62 Mev; γ , 0.161 Mev).
- d. In^{117} - yield 0. $T = 66\text{m}$. Partial decay of $\text{Cd}^{117\text{m}}$. (see Rh^{117} for decay) (β , 0.740 Mev; γ , 0.161, 0.565 Mev).
- e. In^{118} - yield 0. $T = 4.5\text{m}$. (see Rh^{118} for decay) (β , 1.5 Mev; γ).
- f. In^{119} - yield 0.005. $T = 17.5\text{m}$. (see Rh^{119} for decay) (β , 2.7 Mev; no γ).
- g. In^{120} - yield 0.028. $T = 2\text{m}^*$. (see Pd^{120} for decay).
- h. In^{121} - yield 0.089. $T = 75\text{s}^*$. (11.5m ref. 10) (see Pd^{121} for decay) (γ , 0.85 Mev).
- i. In^{122} - yield 0.203. $T = 45\text{s}^*$. (see Pd^{122} for decay).
- j. In^{123} - yield 0.383. $T = 30\text{s}^*$. (see Ag^{123} for decay).
- k. In^{124} - yield 0.636. $T = 20\text{s}^*$. (see Ag^{124} for decay).
- l. In^{125} - yield 1.023. $T = 15\text{s}^*$. (see Ag^{125} for decay).
- m. In^{126} - yield 3.48. $T = 7\text{s}^*$. (see Cd^{126} for decay).
- n. In^{127} - yield 6.92. $T = 3\text{s}^*$. (see Cd^{127} for decay).
- o. In^{128} - yield 16.4. $T = 2\text{s}^*$. (see Cd^{128} for decay).

22. Indium (continued)

p. In^{128} - yield 16.4. $T = 2s^*$. (see Cd^{128} for decay).

q. In^{130} - yield 38.4. $T = 1.5s^*$. $\text{In}^{130} \xrightarrow{1.5s^*} \text{Sn}^{130} \xrightarrow{5s^*} \text{Sb}^{130} \xrightarrow{1m^*} \text{Te}^{130} \text{ (stable)}$

23. Tin - At. No. 50.

a. Sn^{117m} - yield 0, decay of In^{117} to Sn^{117} . $T = 14d$. (IT; γ , 99% 0.159, 0.159, 0.161 Mev, ~1% 0.320 Mev).

b. Sn^{121} - yield 0. $T = 27h$. (see Pd^{121} for decay) (β , 0.383 Mev; no γ).

c. Sn^{123} - yield 0.024. $T = 130d$. (see Ag^{123} for decay) (β , 1.42 Mev; no γ).

d. Sn^{125} - yield 0.338. $T = 10d$. (see Ag^{125} for decay) (β , ~95% 2.37 Mev, ~5% 2 others; γ , 1.97 Mev, 6 others?).

e. Sn^{126} - yield 1.80. $T = 50m$. (see Cd^{126} for decay) (β).

f. Sn^{127} - yield 5.09. $T = 85m$. (see Cd^{127} for decay) (β).

g. Sn^{128} - yield 16.4. $T = 10s^*$. (see Cd^{128} for decay) (β).

h. Sn^{129} - yield 39.2. $T = 5.5s^*$. (see In^{128} for decay).

i. Sn^{130} - yield 82.1. $T = 5s^*$. (see In^{130} for decay) (β).

23. Tin (continued)

j. Sn^{131} - yield 111. $T = 3\text{s}^*$. (see In^{131} for decay) (β).

k. Sn^{132} - yield 113. $T = 2.5\text{s}^*$. (β). $\text{Sn}^{132} \xrightarrow{2.5\text{s}^*} \text{Sb}^{132} \xrightarrow{2.2\text{m}} \text{Te}^{132} \xrightarrow{77.7\text{h}} \text{I}^{132} \xrightarrow{2.4\text{h}} \text{Xe}^{132} \text{ (stable)}$

l. Sn^{133} - yield 86. $T = 2\text{s}^*$. (β).

24. Antimony - At. No. 51

a. Sb^{125} - yield 0.005. $T = 2.7\text{y}$. (see Ag^{125} for decay) (β , 29% 0.125 Mev, 45% 0.300 Mev, 12% 0.444 Mev, 14% 0.612 Mev; γ , 0.427, 0.595, 0.463, 0.637, ~ 6 others).

b. Sb^{126} - yield 0.11. $T = 9\text{h}$. (see Cd^{126} for decay) (β , 1 Mev; γ , 0.9, ~ 4 Mev).

c. Sb^{127} - yield 0.77. $T = 93\text{h}$. (see Cd^{127} for decay) (β , 1.57, 0.86, 1.11 Mev; γ , 0.06, 0.18, 0.24, 0.42, 0.46, 0.56, 0.67, 0.76 Mev).

d. Sb^{128} - yield 4.6. $T = 1.1\text{h}^*$. (see Cd^{128} for decay) (β , 2.9 Mev; γ).

e. Sb^{129} - yield 20.2. $T = 4.2\text{h}$. (see In^{129} for decay) (β , 1.87 Mev, others; γ , 0.16, 0.31, 0.53, 0.79 Mev).

f. Sb^{130} - yield 60.4. $T = 1\text{m}^*$. (see In^{130} for decay) (β).

g. Sb^{131} - yield 127. $T = 23.2\text{m}$. (see In^{131} for decay) (β , 1.1 Mev).

h. Sb^{132} - yield 174. $T = 2.2\text{m}$. (see Sn^{132} for decay) (β).

i. Sb^{133} - yield 261. $T = 4.5\text{m}$. (see Sn^{133} for decay) (β).

. Sb^{134} - yield 271. $T = 10\text{s}^*$. (β). $\text{Sb}^{134} \xrightarrow{10\text{s}^*} \text{Te}^{134} \xrightarrow{44\text{m}} \text{I}^{134} \xrightarrow{54.7\text{m}} \text{Xe}^{134} \text{ (stable)}$

24. Antimony (continued)

k. Sb¹³⁵ - yield 122. T = 6s*.

l. Sb¹³⁶ - yield 54. T = 3s*. $\text{Sb}^{136} \xrightarrow{3s^*} \text{Te}^{136} \xrightarrow{6s^*} \text{I}^{136} \xrightarrow{86s} \text{Xe}^{136} \text{ (stable)}$

25. Tellurium - At. No. 52.

a. Te^{125m} - yield 0. T = 58d. (see Ag¹²⁵ for decay) (IT; γ, 0.110, 0.0354 Mev).

b. Te^{127m} - yield 0. T = 90d. (see Cd¹²⁷ for decay) (98+% IT; γ, 0.0885 Mev; 1.5% β, 0.73 Mev; γ, 0.058 Mev, others).

c. Te¹²⁷ - yield 0. T = 9.3h. (see Cd¹²⁷ for decay) (β, 0.69 Mev, others; γ, 0.42, 0.36 Mev, 4 others).

d. Te^{129m} - yield 0.6. T = 32d. (see In¹²⁹ for decay) (IT; γ, 0.106 Mev).

e. Te¹²⁹ - yield 0.7. T = 70m. (see In¹²⁹ for decay) (β, 71% 1.45 Mev, 29% 3 others; γ, 0.027, 0.21, 0.48, 0.72, 1.12 Mev).

f. Te^{131m} - yield 21. T = 30h. (see In¹³¹ for decay) (22% IT; γ, 0.180 Mev; 78% β, 52% 0.42 Mev, 26% 3 others; γ, 1.12 Mev; 4 others).

g. Te¹³¹ - yield 21. T = 25m. (see In¹³¹ for decay) (β, 13% 2.14 Mev, 9% 2 others - 22% above - ; γ, 0.147, 0.77, 0.33, 4 others).

h. Te¹³² - yield 104. T = 77.7h. (see Sn¹³² for decay) (β, 0.22 Mev; γ, 0.231 Mev).

i. Te^{133m} - yield 119. T = 63m. (see Sn¹³³ for decay) (IT; γ, ~0.4 Mev).

25. Tellurium (continued)

- j. Te¹³³ - yield 119. T = 2m. (see Sn¹³³ for decay) (β , ~70% 1.3 Mev, ~30% 2.4 Mev; 0.6, 1.0 Mev).
 k. Te¹³⁴ - yield 320. T = 44m. (see Sb¹³⁴ for decay) (β).
 l. Te¹³⁵ - yield 259. T = 10s*. (see Sb¹³⁵ for decay) (β).
 m. Te¹³⁶ - yield 223. T = 6s*. (see Sb¹³⁶ for decay) (β).
 n. Te¹³⁷ - yield 175. T = 3s*.

- o. Te¹³⁸ - yield 86. T = 2s*. Te¹³⁸ --2s*--> I¹³⁸ (5.9s) --> Xe¹³⁸ (17m) --> Cs¹³⁸ (33m) --> Ba¹³⁸ (stable)

26. Iodine - At. No. 53

- a. I¹²⁹ - yield 0, decay of Te¹²⁹ to Xe¹²⁹. T = 1.72x10⁷y. (β , 0.150 Mev; γ , 0.039 Mev).
 b. I¹³¹ - yield 1. T = 8.1d. (see In¹³¹ for decay) (β , 87.2% 0.608 Mev, 9.3% 0.335 Mev, 2.8% 0.250 Mev, 0.7% 0.812 Mev; γ , ~3% 0.284 Mev, 9.3% 0.637 Mev, 2.8% 0.722 Mev, others).
 c. I¹³² - yield 9. T = 2.4h. (see Sn¹³² for decay) (β , 18% 2.12 Mev, 24% 1.5 Mev, 23% 1.2 Mev, 35% others; γ , 0.673, 0.777, 0.528, 0.96, 1.40, 1.16, 1.96, 2.2 Mev).
 d. I¹³³ - yield 44. T = 22.4h. (see Sn¹³³ for decay) (β , ~94% 1.4 Mev, ~6% 0.5 Mev; γ , ~94% 0.53 Mev, ~5% 0.85 Mev, ~1% 1.4 Mev).

26. Iodine (continued)

- e. I^{134} - yield 144. $T = 54.7$. (see Sb^{134} for decay) (β , ~70% 1.5 Mev, ~30% 2.5 Mev; γ , 0.86, 1.10, 1.78, 0.127, 0.207 Mev).
- f. I^{135} - yield 191. $T = 6.68h$. (see Sb^{135} for decay) (β , 35% 0.47 Mev, 40% 1.00 Mev, 25% 1.40 Mev; γ , 1.27, 1.8, 2.4 Mev).
- g. I^{136} - yield 249. $T = 86s$. (see Sb^{136} for decay) (β , 6.3, 5.0, 3.7 Mev; γ , 1.38, 2.9 Mev).
- h. I^{137} - yield 270. $T = 22s$. (see Te^{137} for decay) (β).
- i. I^{138} - yield 258. $T = 5.9s$. (see Te^{138} for decay) (β).
- j. I^{139} - yield 205. $T = 2.7s$. (β). $I^{139} \xrightarrow{2.7s} Xe^{139} \xrightarrow{41s} Cs^{139} \xrightarrow{9.5m} Ba^{139} \xrightarrow{85m} La^{139}$ (stable)
- k. I^{140} - yield 84. $T = 1.5s^*$.
 $I^{140} \xrightarrow{1.5s^*} Xe^{140} \xrightarrow{16s} Cs^{140} \xrightarrow{66s} Ba^{140} \xrightarrow{12.8d} La^{140} \xrightarrow{40h} Ce^{140}$ (stable).

27. Xenon - At. No. 54.

- a. Xe^{131m} - yield 0. $T = 12d$. (see In^{131} for decay) (IT; γ , 0.7% 0.163 Mev, 81% 0.364 Mev, 6.3% 0.284 Mev, 6.3% 0.080 Mev).
- b. Xe^{133m} - yield 0. $T = 2.3d$. (see Sn^{133} for decay) (IT; γ , 0.234 Mev).
- c. Xe^{133} - yield 0. $T = 5.27d$. (see Sn^{133} for decay) (β , 0.345 Mev; γ , 0.081 Mev).
- d. Xe^{135m} - yield 14. $T = 15.3m$. (see Sb^{135} for decay) (IT; γ , 0.52 Mev).
- e. Xe^{135} - yield 14. $T = 9.2h$. (see Sb^{135} for decay) (β , 97% 0.905 Mev, ~3% 0.55 Mev; γ , 0.60, 0.36 Mev).
- f. Xe^{137m} - yield 0, 6.8% decay of I^{137} to Xe^{136} . $T = \text{inst.}$ (neutron, 0.67 Mev).
- g. Xe^{137} - yield 150. $T = 3.9m$. (see Te^{137} for decay) (β , 3.5 Mev; γ).

27. Xenon (continued)

h. Xe^{138} - yield 230. $T = 17\text{m}$. (see Te^{138} for decay) (β , 2.68 Mev; γ , 0.42, 0.51, 1.8, 2.0 Mev).

i. Xe^{139} - yield 274. $T = 4\text{ls}$. (see I^{139} for decay) (β).

j. Xe^{140} - yield 249. $T = 16\text{s}$. (see I^{140} for decay) (β).

k. Xe^{141} - yield 196. $T = 2\text{s}$. $\text{Xe}^{141} \xrightarrow{2\text{s}} \text{Cs}^{141} \xrightarrow{9\text{s}^*} \text{Ba}^{141} \xrightarrow{18\text{m}} \text{La}^{141} \xrightarrow{3.7\text{h}} \text{Ce}^{141} \xrightarrow{32.5\text{d}} \text{Pr}^{141} \text{ (stable)}$

l. Xe^{142} - yield 81. $T = 1.5\text{s}^*$. $\text{Xe}^{142} \xrightarrow{1.5\text{s}^*} \text{Cs}^{142} \xrightarrow{4\text{s}^*} \text{Ba}^{142} \xrightarrow{6\text{m}} \text{La}^{142} \xrightarrow{74\text{m}} \text{Ce}^{142} \text{ (stable)}$

28. Cesium - At. No. 55

a. $\text{Cs}^{135\text{m}}$ - yield 0, decay of Xe^{135} to Cs^{135} to Ba^{135} . $T = 2.8 \times 10^{-10}\text{s}$. (IT ; γ , 0.248 Mev).

b. Cs^{135} - yield 0, decay of Xe^{135} to Ba^{135} . $T = 3.0 \times 10^6\text{y}$. (see Sb^{135} for decay) (β , 0.21 Mev; no γ).

c. Cs^{137} - yield 13. $T = 27\text{y}$ (37y ref. 3) (see Te^{137} for decay) (β , 92% 0.523 Mev, 8% 1.19 Mev).

d. Cs^{138} - yield 56. $T = 33\text{m}$. (see Te^{138} for decay) (β , 3.4 Mev, others; γ , 1.43, 0.463, 1.01, 2.21, 2.63, 0.55 Mev, 6 others).

e. Cs^{139} - yield 142. $T = 9.5\text{m}$. (see I^{139} for decay) (β , 3.17 Mev).

f. Cs^{140} - yield 223. $T = 66\text{s}$. (see I^{140} for decay) (β).

g. Cs^{141} - yield 261. $T = 9\text{s}^*$. (see Xe^{141} for decay) (β).

h. Cs^{142} - yield 241. $T = 4\text{s}^*$. (see Xe^{142} for decay) (β).

i. Cs^{143} - yield 182. $T = 2\text{s}^*$. (β , γ , 0.12, 0.29 Mev, others)

$\text{Cs}^{143} \xrightarrow{2\text{s}^*} \text{Ba}^{143} \xrightarrow{6\text{s}^*} \text{La}^{143} \xrightarrow{19\text{m}} \text{Ce}^{143} \xrightarrow{33\text{h}} \text{Pr}^{143} \xrightarrow{13.7\text{d}} \text{Nd}^{143} \text{ (stable)}.$

j. Cs^{144} - yield 68. $T = 1.5\text{s}^*$. (β).

$\text{Cs}^{144} \xrightarrow{1.5\text{s}^*} \text{Ba}^{144} \xrightarrow{3.5\text{s}^*} \text{La}^{144} \xrightarrow{15\text{s}^*} \text{Ce}^{144} \xrightarrow{290\text{d}} \text{Pr}^{144} \xrightarrow{17.5\text{m}} \text{Nd}^{144} \xrightarrow{\alpha, \sim 2 \times 10^{15}\text{y}} \text{Ce}^{144} \text{ (stable)}.$

28. Cesium (continued)

k. Cs^{145} - yield <5% of chain, Present's est. yield 57.0. $T = 1s^*$.

29. Barium - At. No. 56.

a. Ba^{137m} - yield 0. $T = 2.64m$. (see Te^{137} for decay) (IT; γ , 0.6612 Mev).

b. Ba^{139} - yield 9. $T = 85m$. (see I^{139} for decay) (β , 15% 2.38 Mev, 66% 2.22 Mev, 19% 0.82 Mev; γ , 0.163 Mev, 1.43 Mev).

c. Ba^{140} - yield 54. $T = 12.8d$. (see I^{140} for decay) (β , 60% 1.02 Mev, 25% 0.49 Mev, 10% 0.60 Mev, 5% 0.89 Mev; γ , 0.53, 0.03, 0.16, 0.42, 0.3 Mev).

d. Ba^{141} - yield 135. $T = 18m$. (see Xe^{141} for decay) (β , 2.8 Mev; γ).

e. Ba^{142} - yield 215. $T = 6m$. (see Xe^{142} for decay) (β).

f. Ba^{143} - yield 244. $T = 6s^*$. (see Cs^{143} for decay) (β).

g. Ba^{144} - yield 205. $T = 3.5s^*$. (see Cs^{144} for decay) (β).

h. Ba^{145} - yield 143. $T = 2s^*$. (see Cs^{145} for decay).

i. Ba^{146} - yield 64. $T = 1.5s^*$. $\text{Ba}^{146} \xrightarrow{1.5s^*} \text{La}^{146} \xrightarrow{4s^*} \text{Ce}^{146} \xrightarrow{14.6m} \text{Pr}^{146} \xrightarrow{25m} \text{Nd}^{146} \text{ (stable)}$

j. Ba^{147} - yield <5% of chain, Present's est., yield 75.0. $T = 1s^*$.

k. Ba^{148} - yield <5% of chain. Present's est. yield 21.8. $T = 1s^*$.

30. Lanthanum - At. No. 57.

- a. La¹⁴⁰ - yield 0. T = 40h. (see I¹⁴⁰ for decay) (β , ~45% 1.34 Mev, ~10% 1.67 Mev, ~7% 2.15 Mev, ~38% others <1.3 Mev; γ , 1.60, 0.486, 0.815, 0.328, 0.44 Mev ~4 others, 2.5, 3.0 Mev).
- b. La¹⁴¹ - yield 8. T = 3.7h. (see Xe¹⁴¹ for decay) (β , ~95% 2.43 Mev, ~5% 0.9 Mev; γ , ~1.5 Mev).
- c. La¹⁴² - yield 52. T = 74m. (see Xe¹⁴² for decay) (β , >2.5 Mev; γ , 0.63, 0.87 Mev).
- d. La¹⁴³ - yield 126. T = 19m. (see Cs¹⁴³ for decay) (β).
- e. La¹⁴⁴ - yield 182. T = 15s*. (see Cs¹⁴⁴ for decay) (β).
- f. La¹⁴⁵ - yield 191. T = 9s*. (see Cs¹⁴⁵ for decay).
- g. La¹⁴⁶ - yield 160. T = 4s*. (see Ba¹⁴⁶ for decay).
- h. La¹⁴⁷ - yield 106. T = 2s*. (see Ba¹⁴⁷ for decay).
- i. La¹⁴⁸ - yield 44.4. T = 2s*. (see Ba¹⁴⁸ for decay).
- j. La¹⁴⁹ - yield 12.5. T = 1.5s*.

- k. La¹⁵⁰ - yield <5% of chain, Present's est. yield 15.1. T = 1.5s*.

- l. La¹⁵¹ - yield <5% of chain, Present's est. yield 3.70. T = 1s*.

31. Cerium - At. No. 58

- a. Ce¹⁴¹ - yield 0. T = 32.5d. (see Xe¹⁴¹ for decay) (β , 75% 0.432 Mev, 25% 0.576 Mev; γ , 0.145 Mev).
- b. Ce¹⁴³ - yield 8. T = 33h. (see Cs¹⁴³ for decay) (β , 1.09, 1.39 0.71 Mev; γ , 0.035, 0.126, ~0.160, 0.290, 0.356, 0.660, 0.72 Mev, ~5 others).
- c. Ce¹⁴⁴ - yield 45. T = 290d. (see Cs¹⁴⁴ for decay) (β , ~72% 0.304 Mev, ~22% 0.17 Mev, ~3% 0.223 Mev, others?; γ , 0.134, 0.081, 0.094 Mev, 8 others ?).
- d. Ce¹⁴⁵ - yield 99. T = 1.8h. (see Cs¹⁴⁵ for decay) (β , 2.0 Mev; γ).
- e. Ce¹⁴⁶ - yield 130. T = 14.6m. (see Ba¹⁴⁶ for decay) (β , 0.7 Mev; γ , 0.32, 0.22, 0.14, 0.11, 0.27 Mev, 2 others).
- f. Ce¹⁴⁷ - yield 125. T = 9s*. (see Ba¹⁴⁷ for decay).
- g. Ce¹⁴⁸ - yield 95.0. T = 7s*. (see Ba¹⁴⁸ for decay).
- h. Ce¹⁴⁹ - yield 51.1. T = 3.5s*. (see La¹⁴⁹ for decay).
- i. Ce¹⁵⁰ - yield 25.4. T = 2.5s*. (see La¹⁵⁰ for decay).
- j. Ce¹⁵¹ - yield 6.8. T = 2s*. (see La¹⁵¹ for decay).
- k. Ce¹⁵² - yield <5% of chain, Present's est. yield 9.60. T = 1.5s*.

Ce¹⁵² $\xrightarrow{1.5s^*}$ Pr¹⁵² $\xrightarrow{5s^*}$ Nd¹⁵² $\xrightarrow{3m^*}$ Pm¹⁵² $\xrightarrow{1h^*}$ Sm¹⁵² (stable).

- l. Ce¹⁵³ - yield <5% of chain, Present's est. yield 2.06. T = 1.5s*.

Ce¹⁵³ $\xrightarrow{1.5s^*}$ Pr¹⁵³ $\xrightarrow{3s^*}$ Nd¹⁵³ $\xrightarrow{18s^*}$ Pm¹⁵³ $\xrightarrow{9m^*}$ Sm¹⁵³ $\xrightarrow{47h}$ Eu¹⁵³ (stable)
 $\searrow$ IT $\uparrow$ 1.4x10⁻¹⁰s
 Eu^{153m}

31. Cerium (continued)

m. Ce¹⁵⁴ - yield < 5% of chain, Present's est. yield 0.410. T = 1s*.

32. Praseodymium - At. No. 59.

a. Pr¹⁴³ - yield 0. T = 13.7d. (see Cs¹⁴³ for decay) (β , 0.932 Mev; no γ).

b. Pr¹⁴⁴ - yield 0. T = 17.5m. (see Cs¹⁴⁴ for decay) (β , 97% 2.98 Mev, 1% 2.28 Mev, 2% 0.8 Mev; γ , 0.695, 2.18, 1.48 Mev).

c. Pr¹⁴⁵ - yield 6. T = 4.5h. (see Cs¹⁴⁵ for decay) (β , ~1.7 Mev; no γ).

d. Pr¹⁴⁶ - yield 26. T = 25m. (see Ba¹⁴⁶ for decay) (β , 56% 3.7 Mev, 44% 2.2 Mev; γ , 0.46, 1.49, 0.75, 0.59? Mev).

e. Pr¹⁴⁷ - yield 57. T = 4m*. (see Ba¹⁴⁷ for decay).

f. Pr¹⁴⁸ - yield 70.0. T = 80s*. (see Ba¹⁴⁸ for decay).

g. Pr¹⁴⁹ - yield 57.3. T = 30s*. (see La¹⁴⁹ for decay).

h. Pr¹⁵⁰ - yield 39.2. T = 15s*. (see La¹⁵⁰ for decay).

i. Pr¹⁵¹ - yield 20.5. T = 7s*. (see La¹⁵¹ for decay).

j. Pr¹⁵² - yield 11.3. T = 5s*. (see Ce¹⁵² for decay).

k. Pr¹⁵³ - yield 3.82. T = 3s*. (see Ce¹⁵³ for decay).

l. Pr¹⁵⁴ - yield 0.90. T = 2s*. (see Ce¹⁵⁴ for decay).

32. Praseodymium (continued)

m. Pr^{155} - yield < 5% of chain yield. $T = 2\text{s}^*$. (Present's est., yield 0.830).

n. Pr^{156} - yield < 5% of chain yield. $T = 1.5\text{s}^*$. (Present's est., yield 0.168).

33. Neodymium - At. No. 60

a. Nd^{144} - yield 0, decay of Pr^{144} . $T = \sim 2 \times 10^{15}\text{y}$. (Natural isotope of Nd) (α , 1.9 Mev).

b. Nd^{147} - yield 2. $T = 11.6\text{d}$. (see Ba^{147} for decay) (β , ~60% 0.83 Mev, ~15% 0.6 Mev, ~25% 0.38 Mev; γ , 0.0918, 0.53, ~0.32, 0.44 Mev, 6 others).

c. Nd^{149} - yield 18.9. $T = 1.7\text{h}$. (see La^{149} for decay) (β , 0.95, 1.1, 1.5 Mev; γ , 0.096, 0.112, 0.114, 0.124, 0.210, 0.240 Mev, others).

d. Nd^{151} - yield 18.3. $T = 12\text{m}$. (see La^{151} for decay) (β , 1.93 Mev; γ , 0.085, 0.110, 0.117, 0.421, 0.72, 1.14 Mev).

e. Nd^{152} - yield 13.4. $T = 3\text{m}^*$. (see Ce^{152} for decay).

f. Nd^{153} - yield 6.96. $T = 18\text{s}^*$. (see Ce^{153} for decay).

g. Nd^{154} - yield 3.20. $T = 12\text{s}^*$. (see Ce^{154} for decay).

h. Nd^{155} - yield 1.17. $T = 5\text{s}^*$. (see Pr^{155} for decay).

i. Nd^{156} - yield 0.343. $T = 4.5\text{s}^*$. (see Pr^{156} for decay).

j. Nd^{157} - yield 0.100. $T = 3\text{s}^*$. $\text{Nd}^{157} \xrightarrow{3\text{s}^*} \text{Pm}^{157} \xrightarrow{13\text{s}^*} \text{Sm}^{157} \xrightarrow{2\text{m}^*} \text{Eu}^{157} \xrightarrow{15.4\text{m}} \text{Gd}^{157} \text{ (stable)}.$

33. Neodymium (continued)

k. Nd¹⁵⁸ - yield < 5% of chain yield. T = 2s*. (Present's est., yield 0.0630).

l. Nd¹⁵⁹ - yield < 5% of chain yield. T = 1.5s*. (Present's est., yield 0.008).

34. Promethium - At. No. 61

a. Pm¹⁴⁷ - yield 0. T = 3.7y. (see Ba¹⁴⁷ for decay). (β, 0.223 Mev; γ, 0.121 ? Mev).

b. Pm¹⁴⁹ - yield 0.3. T = 47h. (see La¹⁴⁹ for decay) (β, 1.0 Mev; γ, 0.285, ~1.0 Mev).

c. Pm¹⁵⁰ - yield 2.07 (shielded nuclide). T = 2.7h. (β, ~80% 2.0 Mev, ~20% 3.0 Mev; γ, 0.34, 0.43, 0.82, 1.17, 1.32, 2.6, 3.0 Mev, 5 others). $\text{Pm}^{150} \xrightarrow{2.7h} \text{Sm}^{150} \text{ (stable)}.$

d. Pm¹⁵¹ - yield 4.5. T = 27.5h. (see La¹⁵¹ for decay) (β, 1.1 Mev, others; γ, 0.335, 0.275, 0.23, 0.44, 0.70, 0.65 Mev, 12 others).

e. Pm¹⁵² - yield 6.0. T = 1h*. (see Ce¹⁵² for decay).

f. Pm¹⁵³ - yield 4.64. T = 9m*. (see Ce¹⁵³ for decay) (β).

g. Pm¹⁵⁴ - yield 3.20. T = 3m*. (see Ce¹⁵⁴ for decay).

h. Pm¹⁵⁵ - yield 1.38. T = 60s*. (see Pr¹⁵⁵ for decay) (β).

i. Pm¹⁵⁶ - yield 0.734. T = 25s*. (see Pr¹⁵⁶ for decay) (β).

j. Pm¹⁵⁷ - yield 0.303. T = 13s*. (see Nd¹⁵⁷ for decay).

k. Pm¹⁵⁸ - yield 0.109. T = 6s*. (see Nd¹⁵⁸ for decay).

34. Promethium (continued)

1. Pm^{159} - yield 0.0223. $T = 3.5\text{s}^*$. (see Nd^{159} for decay).
- m. Pm^{160} - yield 0.0051. $T = 2.5\text{s}^*$. $\text{Pm}^{160} \xrightarrow{2.5\text{s}^*} \text{Sm}^{160} \xrightarrow{15\text{s}^*} \text{Eu}^{160} \xrightarrow{70\text{s}^*} \text{Gd}^{160}$ (stable).
- n. Pm^{161} - yield < 5% of chain yield. $T = 2\text{s}^*$. (Present's est., yield 0.00151).
 $\text{Pm}^{161} \xrightarrow{2\text{s}^*} \text{Sm}^{161} \xrightarrow{4\text{s}^*} \text{Eu}^{161} \xrightarrow{22\text{s}^*} \text{Gd}^{161} \xrightarrow{3.6\text{m}} \text{Tb}^{161} \xrightarrow{6.8\text{d}} \text{Dy}^{161}$ (stable).

35. Samarium - At. No. 62.

- a. Sm^{147} - yield 0, decay of Pm^{147} . $T = 1.3 \times 10^{11}\text{y}$. (Natural isotope of Sm) (α , 2.18 Mev).
- b. Sm^{151} - yield 0. $T = 73\text{y}$. (see La^{151} for decay) (β , 0.075 Mev; γ , 0.020 Mev).
- c. Sm^{153} - yield 0.58. $T = 47\text{h}$. (see Ce^{153} for decay) (β , ~50% 0.72 Mev, ~30% 0.65 Mev, ~20% 0.82 Mev, others?; γ , 0.172, 0.54 Mev, ~4 others).
- d. Sm^{155} - yield 0.62. $T = 25\text{m}$. (see Pr^{155} for decay) (β , 1.8 Mev; γ , 0.105, 0.246 Mev).
- e. Sm^{156} - yield 0.541. $T = 10\text{h}$. (see Pr^{156} for decay) (β , 0.9 Mev).
- f. Sm^{157} - yield 0.270. $T = 2\text{m}^*$. (see Nd^{157} for decay).
- g. Sm^{158} - yield 0.130. $T = 15\text{m}^*$. (see Nd^{158} for decay).
- h. Sm^{159} - yield 0.0475. $T = 14\text{s}^*$. (see Nd^{159} for decay).
- i. Sm^{160} - yield 0.0155. $T = 15\text{s}^*$. (see Pm^{160} for decay).
- j. Sm^{161} - yield 0.00370. $T = 4\text{s}^*$. (see Pm^{161} for decay).

36. Europium - At. No. 63.

- a. $\text{Eu}^{153\text{m}}$ - yield 0, decay of Sm^{153} to Eu^{153} . $T = 1.4 \times 10^{-10}\text{s}$. (IT; γ , 0.069, 0.103 Mev).

36. Europium (continued)

- b. Eu¹⁵⁵ - yield 0.02. T = 2y. (see Pr¹⁵⁵ for decay) (β , 84% 0.152 Mev, 16% 0.252 Mev; γ , 0.060 0.086, 0.105, 0.131 Mev, others).
- c. Eu¹⁵⁶ - yield 0.082. T = 15.4d. (see Pr¹⁵⁶ for decay) (β , 60% 0.4 Mev, 40% 2.4 Mev; γ , 2.0 Mev).
- d. Eu¹⁵⁷ - yield 0.066. T = 15.4m. (see Nd¹⁵⁷ for decay) (β , 75% 1.0 Mev, 25% ~1.7 Mev; γ , 0.2, 0.6 Mev).
- e. Eu¹⁵⁸ - yield 0.059. T = 1h. (see Nd¹⁵⁸ for decay) (β , 2.6 Mev; γ).
- f. Eu¹⁵⁹ - yield 0.0350. T = 5m. (see Nd¹⁵⁹ for decay).
- g. Eu¹⁶⁰ - yield 0.0139. T = 70s*. (see Pm¹⁶⁰ for decay).
- h. Eu¹⁶¹ - yield 0.00378. T = 22s*. (see Pm¹⁶¹ for decay).

37. Gadolinium - At. No. 64.

- a. Gd¹⁵⁹ - yield 0.0053. T = 18h. (see Nd¹⁵⁹ for decay). (β , ~76% 0.95 Mev, 16% 0.60 Mev, ~8% 0.89 Mev; γ , 0.364, 0.056, 0.23, 0.136, 0.079 Mev).
- b. Gd¹⁶¹ - yield 0.00149. T = 3.6m. (see Pm¹⁶¹ for decay) (β , ~1.6 Mev; γ , 0.102, 0.316, 0.36 Mev).

38. Terbium - At. No. 65.

- a. Tb¹⁶¹ - yield 0.0000360. T = 6.8d. (see Pm¹⁶¹ for decay) (β , 0.53 Mev, 2 others; γ , 0.026, 0.049, 0.075, 0.028, 0.057, 0.078, 0.106 Mev).

APPENDIX A - (Continued)

II. Fission Product Abundances at Various Times

The following table of abundances of fission products has been derived from the data of reference 3. Abundances at various times up to one year are given in terms of megacuries per megaton of fission. A factor of 10^{26} fissions per MT was used in these calculations. The letter "a" indicates values less than 1 curie/MT. At the end of the table are some additional decay products which are not given in reference 3.

Nuclide	$T_{1/2}$	Max Mc/MT	Time at Max.	Mc/MT at 1 hr	Mc/MT at 1 day	Mc/MT at 1 month	Mc/MT at 1 yr.
Ni ⁷²	3.5s*	28	0	a			
Ni ⁷³	2s*	189	0	a			
Ni ⁷⁴	1.5s*	274	0	a			
Cu ⁷²	10s*	14.5	3s	a			
Cu ⁷³	7s*	120	1s	a			
Cu ⁷⁴	4s*	424	0	a			
Cu ⁷⁵	2.5s*	2,110	0	a			
Cu ⁷⁶	2s*	3,650	0	a			
Cu ⁷⁷	1.5s*	6,620	0	a			
Zn ⁷²	49h	0.00167	1.47-6.77m	0.00165	0.0012	1.21×10^{-5}	a
Zn ⁷³	45s*	28.2	19s	a			
Zn ⁷⁴	4.5s*	14.0	19s	0.0014	a		
Zn ⁷⁵	9.5s*	978	3s	a			

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Nuclide	T _{1/2}	Max Mc/MT	Time at Max.	Mc/MT at 1 hr	Mc/MT at 1 day	Mc/MT at 1 month	Mc/MT at 1 yr.
Zn ⁷⁶	8s*	2,260	1s	a			
Zn ⁷⁷	3.5s*	11,720	0	a			
Zn ⁷⁸	2.5s*	31,600	0	a			
Zn ⁷⁹	1.5s*	80,000	0	a			
Zn ⁸⁰	1.5s*	61,250	0	a			
Ga ⁷²	1h.3h	0.00102	1.45d	0.000157	0.000972	a	
Ga ⁷³	5h	0.102	6.77m	0.0907	0.00378	a	
Ga ⁷⁴	4.5m*	6.35	4.62m	0.013	a		
Ga ⁷⁵	70s*	191	28s	a			
Ga ⁷⁶	30s*	832	19s	a			
Ga ⁷⁷	15s*	4,245	6s	a			
Ga ⁷⁸	8s*	16,720	2s	a			
Ga ⁷⁹	4.5s*	66,500	0	a			
Ga ⁸⁰	3s*	154,200	0	a			
Ga ⁸¹	2s*	397,500	0	a			
Ga ⁸²	1.5s*	476,000	0	a			

Nuclide	$T_{1/2}$	Max Mc/MT	Time at Max.	Mc/MT at 1 hr.	Mc/MT at 1 day	Mc/MT at 1 month	Mc/MT at 1 yr.
Ge ⁸³	2s*	1,743,000	0	a			
Ge ⁸⁴	1.5s*	2,020,000	0	a			
Ge ⁸⁵	1s*	2,700,000	0	a			
As ⁷⁷	40h	0.516	11.1h	0.475	0.483	1.89×10^{-6}	a
As ⁷⁸	90m	16.1	2.40h	11.9	0.0486	a	
As ⁷⁹	9m	1,130	2.15m	13.5	a		
As ⁸⁰	2m*	7,380	1m	4.6×10^{-6}	a		
As ⁸¹	50s*	39,750	19s	a			
As ⁸²	18s*	165,000	9s	a			
As ⁸³	7s*	708,000	3s	a			
As ⁸⁴	4s*	1,618,000	0	a			
As ⁸⁵	2.5s*	3,820,000	0	a			
As ⁸⁶	2s*	5,300,000	0	a			
As ⁸⁷	1.5s*	4,760,000	0	a			
Se ^{81m}	57m	46.8	4.62m	24.3	1.8×10^{-6}	a	
Se ⁸¹	13.6m	2,680	3.15m	194.5	2.2×10^{-5}	a	
Se ^{83m}	67s	60,000	28s	a			
Se ⁸³	25m	2,720	1m	461	a		

Nuclide	T _{1/2}	Max Mc/MT	Time at Max.	Mc/MT at 1 hr.	Mc/MT at 1 day	Mc/MT at 1 month	Mc/MT at 1 yr.
Se ⁸⁴	2m	105,800	19s	5.4x10 ⁻⁵	a		
Se ⁸⁵	9s*	1,500,000	4s	a			
Se ⁸⁶	7s*	2,600,000	2s	a			
Se ⁸⁷	3s*	6,860,000	0	a			
Se ⁸⁸	2.5s*	8,540,000	0	a			
Se ⁸⁹	2s*	7,325,000	0	a			
Br ⁸³	2.4h	805	45.8m	786	1.08	a	
Br ⁸⁴	33m	6,270	9.92m	2,270	a		
Br ⁸⁵	3m	115,500	41s	0.073	a		
Br ⁸⁶	32s*	742,500	19s	a			
Br ⁸⁷	55.6s	724,500	13s	a			
Br ⁸⁸	15.5s	2,370,000	4s	a			
Br ⁸⁹	4.51s	8,080,000	0	a			
Br ⁹⁰	3s*	11,670,000	0	a			
Br ⁹¹	2s*	8,625,000	0	a			
Br ⁹²	1.5s*	4,870,000	0	a			
Kr ^{83m}	1.9h	454	3.52h	230	4.9	a	
Kr ^{85m}	4.36h	1,210	21.3m	1,110	28.9	a	

Nuclide	T _{1/2}	Max Mc/MT	Time at Max.	Mc/MT at 1 hr.	Mc/MT at 1 day	Mc/MT at 1 month	Mc/MT at 1 yr.
Kr ⁸⁵	9.4y	0.0256	3.12-4.57d	0.0163	0.0253	0.0254	0.0240
Kr ⁸⁷	78m	10,380	6.77m	6,500	0.00864	a	
Kr ⁸⁸	2.77h	7,400	2.15-3.15m	5,860	2.14	a	
Kr ⁸⁹	3.16m	337,500	19s	1.13	a		
Kr ⁹⁰	33s	1,850,000	9s	a			
Kr ⁹¹	9.8s	4,540,000	2s	a			
Kr ⁹²	3s	12,440,000	0	a			
Kr ⁹³	2s	11,350,000	0	a			
Kr ⁹⁴	1.4s	5,610,000	0	a			
Rb ⁸⁸	17.8m	5,780	1.12h	5780	21.8	a	
Rb ⁸⁹	15.4m	54,500	9.92m	7,020	a		
Rb ⁹⁰	2.7m	392,000	1.47m	9.2x10 ⁻⁵	a		
Rb ⁹¹	100s	367,000	28s	a			
Rb ^{91m}	14m	52,900	60s	2,840	a		
Rb ⁹²	17s*	3,735,000	6s	a			
Rb ⁹³	7s*	7,000,000	1s	a			
Rb ⁹⁴	3s*	12,730,000	0	a			
Rb ⁹⁵	2s*	14,100,000	0	a			

Nuclide	T _{1/2}	Max Mc/MT	Time at Max.	Mc/MT at 1 hr.	Mc/MT at 1 day	Mc/MT at 1 month	Mc/MT at 1 yr.
Rb ⁹⁶	1s*	10,810,000	0	a			
Sr ⁸⁹	53d	16.5	3.52h	15.1	16.35	11.2	0.134
Sr ⁹⁰	19.9y	0.152	31.2m-9.82d	0.152	0.152	0.151	0.146
Sr ⁹¹	9.7h	2,630	1.12h	2,620	534	a	
Sr ⁹²	2.7h	10,970	2.15-3.15m	8,590	25.1	a	
Sr ⁹³	7m	237,500	41s	656	a		
Sr ⁹⁴	2m	730,000	13s	0.0014	a		
Sr ⁹⁵	6s*	8,920,000	1s	a			
Sr ⁹⁶	2.5s*	17,500,000	0	a			
Sr ⁹⁷	1.5s*	22,400,000	0	a			
Sr ⁹⁸	1s*	12,700,000	0	a			
Sr ⁹⁹ (P)	1s*	8,510,000	0	a			
Y ⁹⁰	61h	0.151	21.1-45.3d	0.00173	0.03595	0.151	0.146
Y ^{91m}	51m	912	3.52h	526	232	a	
Y ⁹¹	57d	19.8	3.12d	0.81	16.4	14.2	0.243
Y ⁹²	3.5h	3,540	5.16h	1,728	256	a	
Y ⁹³	10h	2,960	45.8m	2,930	605	a	
Y ⁹⁴	16.5m	87,300	6.77m	10,520	a		

Nuclide	T _{1/2}	Max Mc/MT	Time at Max.	Mc/MT at 1 hr.	Mc/MT at 1 day	Mc/MT at 1 month	Mc/MT at 1 yr.
Y ⁹⁵	60s*	1,461,000	19s	a			
Y ⁹⁶	10s*	6,680,000	4s	a			
Y ⁹⁷	5s*	11,410,000	1-2s	a			
Y ⁹⁸	2.5s*	18,100,000	0	a			
Y ⁹⁹	1.5s*	21,100,000	0	a			
Y ¹⁰⁰	1.5s*	9,725,000	0	a			
Y ¹⁰¹ (P)	1s*	15,330,000	0	a			
Zr ⁹⁵	65d	20.95	14.5-45.8m	20.95	20.55	15.1	0.432
Zr ⁹⁷	17h	1900	60s	1,835	724	a	
Zr ⁹⁸	15s*	4,860,000	6s	a			
Zr ⁹⁹	5.5s*	9,950,000	2s	a			
Zr ¹⁰⁰	3.5s*	12,470,000	0	a			
Zr ¹⁰¹	2.5s*	13,400,000	0	a			
Zr ¹⁰²	2s*	7,970,000	0	a			
Zr ¹⁰³	1.5s*	6,340,000	0	a			
Nb ^{95m}	90h	0.444	14.4d	0.0030	0.0665	0.308	0.011
Nb ⁹⁵	35d	10.18	66.4d	0.0156	0.397	7.84	0.892
Nb ^{97m}	60s.	21,950	0	1,840	726	a	

Nuclide	T _{1/2}	Max Mc/MT	Time at Max.	Mc/MT at 1 hr.	Mc/MT at 1 day	Mc/MT at 1 month	Mc/MT at 1 yr.
Nb ⁹⁷	74m	1,579	5.16h	1,122	784	a	
Nb ⁹⁸	30m	61,900	1.47m	16,200	a		
Nb ⁹⁹	2.5m	644,000	28s	0.045	a		
Nb ¹⁰⁰	27s*	2,642,000	9s	a			
Nb ¹⁰¹	11s*	4,560,000	4s	a			
Nb ¹⁰²	7s*	5,025,000	1s	a			
Nb ¹⁰³	4s*	6,210,000	0	a			
Nb ¹⁰⁴	3s*	4,260,000	0	a			
Nb ¹⁰⁵	2s	1,585,000	0	a			
Nb ¹⁰⁶	1.5s*	549,000	0	a			
Nb ^{107(P)}	1s*	375,000	0	a			
Mo ⁹⁹	68.3h	454	21.3-45.8m	452	359	0.302	a
Mo ¹⁰¹	14.6m	98,000	1m	6140	a		
Mo ¹⁰²	11m	108,000	41s	2,620	a		
Mo ¹⁰³	25s*	1,613,000	9s	a			
Mo ¹⁰⁴	18s*	1,232,000	6s	a			
Mo ¹⁰⁵	6s*	1,318,000	1s	a			
Mo ¹⁰⁶	4s*	856,000	0	a			

Nuclide	$T_{1/2}$	Max Mc/MT	Time at Max.	Mc/MT at 1 hr.	Mc/MT at 1 day	Mc/MT at 1 month	Mc/MT at 1 yr.
Mo ¹⁰⁷	2.5s*	489,000	0	a			
Mo ¹⁰⁸	2s*	105,000	0	a			
Mo ¹⁰⁹	1.5s*	31,350	0	a			
Mo ¹¹⁰ (P)	1s*	27,800	0	a			
Tc ^{99m}	5.9h	46.9	23.8h	6.08	46.9	0.0416	a
Tc ¹⁰¹	15m	38,000	21.3m	17,300	a		
Tc ¹⁰²	100s*	85,400	4.62m	3,080	a		
Tc ¹⁰³	60s*	562,000	1m	a			
Tc ¹⁰⁴	30s*	602,500	28s	a			
Tc ¹⁰⁵	15s*	638,000	9s	a			
Tc ¹⁰⁶	9s*	497,500	4s	a			
Tc ¹⁰⁷	6s*	292,000	2s	a			
Tc ¹⁰⁸	3.5s*	148,000	0	a			
Tc ¹⁰⁹	2.5s*	76,500	0	a			
Tc ¹¹⁰	2s*	61,000	0	a			
Tc ¹¹¹	1.5s*	33,800	0	a			
Tc ¹¹²	1.5s*	15,600	0	a			
Ru ¹⁰³	39.8d	18.54	14.5m-1.12h	18.54	18.20	11.03	0.0316

Nuclide	$T_{1/2}$	Max Mc/MT	Time at Max.	Mc/MT at 1 hr.	Mc/MT at 1 day	Mc/MT at 1 month	Mc/MT at 1 yr.
Ru ¹⁰⁵	4.5h	1,150	2.15-3.15m	994	294	a	
Ru ¹⁰⁶	1y	0.297	1.47m-2.13d	0.297	0.297	0.281	0.148
Ru ¹⁰⁷	4m	13,920	28s	0.421	a		
Ru ¹⁰⁸	6m*	3,050	19-28s	3.08	a		
Ru ¹⁰⁹	16s*	20,200	6s	a			
Ru ¹¹⁰	10s*	20,200	3s	a			
Ru ¹¹¹	4s*	31,350	0	a			
Ru ¹¹²	3s*	31,850	0	a			
Ru ¹¹³	2s*	42,600	0	a			
Ru ¹¹⁴	1.5s*	32,950	0	a			
Ru ¹¹⁵	1s*	22,650	0	a			
Rh ^{103m}	57m	18.4	11.1h	11.75	18.2	11.0	0.0316
Rh ^{105m}	45s	1,138	6.77m	994	29.4	a	
Rh ¹⁰⁵	36.5h	106	16.2h	19.42	98.75	0.00337	a
Rh ¹⁰⁶	30s	0.297	4.62m-2.13d	0.297	0.297	0.281	0.148
Rh ¹⁰⁷	26m	1,697	14.5m	572	a		
Rh ¹⁰⁸	80s*	2.260	3.15m	3.975	a		
Rh ¹⁰⁹	40s*	6,975	41s	a			

Nuclide	T _{1/2}	Max Mc/MT	Time at Max.	Mc/MT at 1 hr.	Mc/MT at 1 day	Mc/MT at 1 month	Mc/MT at 1 yr.
Rh ¹¹⁰	20s*	9,190	19s	a			
Rh ¹¹¹	12s*	13,330	9s	a			
Rh ¹¹²	7s*	17,950	4s	a			
Rh ¹¹³	4s*	28,350	1s	a			
Rh ¹¹⁴	3s*	35,100	0	a			
Rh ¹¹⁵	2.5s*	32,150	0	a			
Rh ¹¹⁶	2s*	32,650	0	a			
Rh ¹¹⁷	1.5s*	29,800	0	a			
Rh ¹¹⁸	1.5s*	18,850	0	a			
Rh ¹¹⁹	1.5s*	10,240	0	a			
Pd ¹⁰⁹	13h	11.12	6.77-9.92m	10.6	3.16	a	
Pd ¹¹¹	26m	184.5	1.47m	39.4	a		
Pd ¹¹²	21h	3.46	1.0-9.92m	3.36	1.58	a	
Pd ¹¹³	55s*	3.760	19s	a			
Pd ¹¹⁴	60s*	3,295	13s	a			
Pd ¹¹⁵	13s*	9,625	6s	a			
Pd ¹¹⁶	10s*	11,000	3s	a			
Pd ¹¹⁷	5s*	17,300	1s	a			

Nuclide	T _{1/2}	Max Mc/MT	Time at Max.	Mc/MT at 1 hr.	Mc/MT at 1 day	Mc/MT at 1 month	Mc/MT at 1 yr.
Pd ¹¹⁸	4.5s*	18,700	0	a			
Pd ¹¹⁹	3s*	25,750	0	a			
Pd ¹²⁰	2s*	31,700	0	a			
Pd ¹²¹	1.5s*	27,550	0	a			
Pd ¹²²	1.5s	16,710	0	a			
Ag ^{109m}	39s	11.08	6.77-14.5m	10.70	3.16	a	
Ag ¹¹¹	7.6d	0.454	3.52h	0.359	0.419	0.0292	a
Ag ¹¹²	3.2h	2.46	11.1h	0.702	1.922	a	
Ag ¹¹³	5.3h	13.49	6.77-9.92m	12.10	0.621	a	
Ag ¹¹⁴	2m	1,014	2.15m	a			
Ag ¹¹⁵	20m	163.2	1.47m	21.6	a		
Ag ¹¹⁶	2m*	1,290	41s	a			
Ag ¹¹⁷	50s*	2,780	19s	a			
Ag ¹¹⁸	25s*	5,160	9-13s	a			
Ag ¹¹⁹	17s*	7,750	6s	a			
Ag ¹²⁰	6s*	17,610	2s	a			

Nuclide	$T_{1/2}$	Max Mc/MT	Time at Max.	Mc/MT at 1 hr.	Mc/MT at 1 day	Mc/MT at 1 month	Mc/MT at 1 yr.
Ag ¹²¹	4s*	25,500	0	a			
Ag ¹²²	3s*	34,200	0	a			
Ag ¹²³	2.5s*	41,300	0	a			
Ag ¹²⁴	2s*	37,800	0	a			
Ag ¹²⁵	2s*	20,900	0	a			
Cd ^{115m}	42.6d	0.00364	3.52-11.1h	0.00316	0.003595	0.00225	1.08x10 ⁻⁵
Cd ¹¹⁵	2.33d	0.92	2.40h	0.815	0.711	0.000118	a
Cd ¹¹⁷	2.72h	18.63	6.77m	15.00	0.0432	a	
Cd ¹¹⁸	10y*	0.000654	4.62m-4.57d	0.000654	0.000654	0.000648	0.000613
Cd ¹¹⁹	3m*	970	1m	0.0013	a		
Cd ¹²⁰	12m*	292	41s	9.56	a		
Cd ¹²¹	25s*	6,485	9s	a			
Cd ¹²²	40s*	4,810	9s	a			
Cd ¹²³	9s*	17,900	3s	a			
Cd ¹²⁴	10s*	17,600	2s	a			
Cd ¹²⁵	5s*	34,300	0	a			
Cd ¹²⁶	3s*	163,000	0	a			
Cd ¹²⁷	1.5s*	405,000	0	a			

Nuclide	T _{1/2}	Max Mc/MT	Time at Max.	Mc/MT at 1 hr.	Mc/MT at 1 day	Mc/MT at 1 month	Mc/MT at 1 yr.
Cd ¹²⁸	1s*	862,000	0	a			
In ^{115m}	4.53h	0.484	16.2h	0.119	0.481	8.8x10 ⁻⁵	a
In ¹¹⁷	1.95h	8.25	3.52h	4.97	0.143	a	
In ¹¹⁸	4.5m	0.000654	45.8m-4.57d	0.000654	0.000654	0.000649	0.000616
In ¹¹⁹	17.5m	148.5	9.92m	24.3	a		
In ¹²⁰	2m*	216.5	6.77m	11.4	a		
In ¹²¹	75s*	1,860	1m	a			
In ¹²²	45s*	2,420	1m	a			
In ¹²³	30s*	6,160	19s	a			
In ¹²⁴	20s*	9,080	13s	a			
In ¹²⁵	15s*	16,100	6s	a			
In ¹²⁶	7s*	99,750	2s	a			
In ¹²⁷	3s*	432,000	0	a			
In ¹²⁸	2s*	317,500	0	a			
In ¹²⁹	1.5s*	3,660,000	0	a			
In ¹³⁰	1.5s*	4,790,000	0	a			
In ¹³¹	1s*	5,050,000	0	a			
Sn ¹²¹	27h	2.48	9.92-31.2m	2.44	1.35	a	
Sn ¹²³	130d	0.0270	4.62m-1.45d	0.0270	0.0270	0.0234	0.0043

Nuclide	$T_{1/2}$	Max Mc/MT	Time at Max.	Mc/MT at 1 hr.	Mc/MT at 1 day	Mc/MT at 1 month	Mc/MT at 1 yr.
Sn ¹²⁵	10d	0.540	2.15m-1.12h	0.540	0.503	0.066	a
Sn ¹²⁶	50m	486	1m	214	a		
Sn ¹²⁷	85m	556	28-60s	343	0.00478	a	
Sn ¹²⁸	10s*	470,000	4s	a			
Sn ¹²⁹	5.5s*	1,560,000	2s	a			
Sn ¹³⁰	5s*	2,622,000	0	a			
Sn ¹³¹	3s*	6,920,000	0	a			
Sn ¹³²	2.5s*	8,450,000	0	a			
Sn ¹³³	2s*	8,060,000	0	a			
Sb ¹²⁵	2.7y	0.00524	66.4d	2.68×10^{-5}	0.000375	0.00472	0.00424
Sb ¹²⁶	9h	36.2	3.52h	24.85	8.10	a	
Sb ¹²⁷	93h	8.37	7.56h	3.64	7.61	0.0418	a
Sb ¹²⁸	66m*	198.0	2.15-3.15m	181.2	44.3	a	
Sb ¹²⁹	4.2h	1,093	1-1.47m	930	22.95	a	
Sb ¹³⁰	60s*	451,000	19s	a			
Sb ¹³¹	23.2m	35,100	19-28s	5,910	a		
Sb ¹³²	2.2m	378,000	9-13s	0.034	a		
Sb ¹³³	4.5m	233,000	9s	23.55	a		

Nuclide	T _{1/2}	Max Mc/MT	Time at Max.	Mc/MT at 1 hr.	Mc/MT at 1 day	Mc/MT at 1 month	Mc/MT at 1 yr.
Sb ¹³⁴	10s*	5,070,000	0	a			
Sb ¹³⁵	6s*	3,820,000	0	a			
Sb ¹³⁶	3s*	3,365,000	0	a			
Te ^{125m}	58d	0.000786	208-301d	0	0	0.000175	7.56x10 ⁻⁴
Te ^{127m}	90d	0.0689	21.1d	0.00226	0.0119	0.0656	0.00775
Te ¹²⁷	9.3h	5.51	1.45d	0.128	5.14	0.101	0.00486
Te ^{129m}	32d	1.260	1.45d	0.228	1.252	0.684	4.54x10 ⁻⁴
Te ¹²⁹	70m	526	2.40-3.52h	372	23.75	0.0685	4.7x10 ⁻⁴
Te ^{131m}	30h	55.9	1.64h	54.0	34.3	1.3x10 ⁻⁶	a
Te ¹³¹	25m	13,080	31.2m	10,400	35.1	a	
Te ¹³²	77.7h	261.0	21.3m	260.0	211.5	0.414	a
Te ^{133m}	63m	18,800	14.5m	12,500	0.00351	a	
Te ¹³³	2m	186,000	0	12,980	0.0359	a	
Te ¹³⁴	44m	41,100	1-1.47m	16,320	7.45x10 ⁻⁶	a	
Te ¹³⁵	10s*	4,835,000	0	a			
Te ¹³⁶	6s*	6,990,000	0	a			
Te ¹³⁷	3s*	10,910,000	0	a			
Te ¹³⁸	2s*	8,050,000	0	a			
I ¹³¹	8.1d	73.2	5.16h	38.9	71.4	6.37	a

Nuclide	$T_{1/2}$	Max Mc/MT	Time at Max.	Mc/MT at 1 hr.	Mc/MT at 1 day	Mc/MT at 1 month	Mc/MT at 1 yr.
I ¹³²	2.4h	243.0	7.56h	204	218.5	0.419	a
I ¹³³	22.4h	1,252	3.52h	850	718	a	
I ¹³⁴	54.7m	17,300	45.8m	17,250	0.050	a	
I ¹³⁵	6.68h	4,430	1.47-3.15m	4,020	378	a	
I ¹³⁶	86s	941,000	19s	a			
I ¹³⁷	22s	2,895,000	6s	a			
I ¹³⁸	5.9s	8,150,000	0	a			
I ¹³⁹	2.7s	14,210,000	0	a			
I ¹⁴⁰	1.5s*	10,300,000	0	a			
Xe ^{131m}	12d	0.256	14.4d	0.00443	0.0405	0.1782	a
Xe ^{133m}	2.3d	7.61	2.13d	0.426	6.24	0.286	a
Xe ¹³³	5.27d	175.4	3.12d	0.426	119.9	6.24	a
Xe ^{135m}	15.3m	2,835	4-19s	1,363	118.9	a	
Xe ¹³⁵	9.2h	1,450	11.1h	418	1,000	a	
Xe ¹³⁷	3.9m	354,000	1.47m	12.02	a		
Xe ¹³⁸	17m	102,100	41s	9,340	a		
Xe ¹³⁹	41s	1,250,000	0-1s	a			
Xe ¹⁴⁰	16s	2,910,000	0	a			

Nuclide	T _{1/2}	Max Mc/MT	Time at Max.	Mc/MT at 1 hr.	Mc/MT at 1 day	Mc/MT at 1 month	Mc/MT at 1 yr.
Xe ¹⁴¹	2s	18,350,000	0	a			
Xe ¹⁴²	1.5s	10,100,000	0	a			
Cs ¹³⁷	37y	0.0927	45.8m-45.3d	0.0927	0.0927	0.0927	0.0910
Cs ¹³⁸	33m	29,400	31.2m	23,750	a		
Cs ¹³⁹	9.5m	196,000	28s	2,595	a		
Cs ¹⁴⁰	66s	1,027,000	28s	a			
Cs ¹⁴¹	9s*	6,610,000	3s	a			
Cs ¹⁴²	4s*	11,240,000	0	a			
Cs ¹⁴³	2s*	17,050,000	0	a			
Cs ¹⁴⁴	1.5s*	8,500,000	0	a			
Cs ^{145(P)}	1s*	10,680,000	0	a			
Ba ^{137m}	2.64m	0.0854	1.112h-1.45d	0.0852	0.0854	0.0851	0.0836
Ba ¹³⁹	85m	17,500	31.2m	15,460	0.0486	a	
Ba ¹⁴⁰	12.8d	103.3	21.3m	103.1	97.7	20.25	3.97x10 ⁻⁶
Ba ¹⁴¹	18m	98,500	1m	10,280	a		
Ba ¹⁴²	6m	266,000	28s	267.5	a		
Ba ¹⁴³	6s*	8,560,000	2s	a			
Ba ¹⁴⁴	3.5s*	10,980,000	0	a			

Nuclide	$T_{1/2}$	Max Mc/MT	Time at Max.	Mc/MT at 1 hr.	Mc/MT at 1 day	Mc/MT at 1 month	Mc/MT at 1 yr.
Ba ¹⁴⁵	2s*	13,400,000	0	a			
Ba ¹⁴⁶	1.5s*	8,000,000	0	a			
Ba ¹⁴⁷ (P)	1s*	14,050,000	0	a			
Ba ¹⁴⁸ (P)	1s*	4,100,000	0	a			
La ¹⁴⁰	40h	75.4	6.70d	1.697	33.78	23.4	a
La ¹⁴¹	3.7h	6,750	1.12h	6,640	108.0	a	
La ¹⁴²	74m	19,880	21.3m	15,400	0.0351	a	
La ¹⁴³	19m	88,000	41s	10,200	a		
La ¹⁴⁴	15s*	3,640,000	9s	a			
La ¹⁴⁵	9s*	4,840,000	3s	a			
La ¹⁴⁶	4s*	7,480,000	0	a			
La ¹⁴⁷	2s*	9,940,000	0	a			
La ¹⁴⁸	2s*	4,130,000	0	a			
La ¹⁴⁹	1.5s*	1,560,000	0	a			
La ¹⁵⁰ (P)	1.5s*	1,885,000	0	a			
La ¹⁵¹ (P)	1s*	691,000	0	a			
Ce ¹⁴¹	32.5d	38.9	23.8h-1.45d	4.13	38.9	21.35	0.0162
Ce ¹⁴³	33h	843.0	2.40h	764.0	540	0.00445	a
Ce ¹⁴⁴	290d	3.72	2.15m-2.13d	3.72	3.72	3.48	1.567

Nuclide	T _{1/2}	Max. Mc/MT	Time at Max.	Mc/MT at 1 hr.	Mc/MT at 1 day	Mc/MT at 1 month	Mc/MT at 1 yr.
Ce ¹⁴⁵	1.8h	12,400	1.47m	8,540	1.350	a	
Ce ¹⁴⁶	14.6m	73,600	28s	4,185	a		
Ce ¹⁴⁷	9s*	3,320,000	3s	a			
Ce ¹⁴⁸	7s*	2,625,000	1s	a			
Ce ¹⁴⁹	3.5s*	2,725,000	0	a			
Ce ¹⁵⁰	2.5s*	1,900,000	0	a			
Ce ¹⁵¹	2s*	637,000	0	a			
Ce ¹⁵² (P)	1.5s*	1,199,000	0	a			
Ce ¹⁵³ (P)	1.5s*	257,000	0	a			
Ce ¹⁵⁴ (P)	1s*	76,600	0	a			
Pr ¹⁴³	13.7d	68.4	4.57d	0.994	33.45	21.85	a
Pr ¹⁴⁴	17.5m	3.72	2.40h-2.13d	3.32	3.72	3.495	1.291
Pr ¹⁴⁵	4.5h	2,725	3.52h	1,508	213.5	a	
Pr ¹⁴⁶	25m	22,000	21.3m	14,460	a		
Pr ¹⁴⁷	4m*	197,200	41s	74.4	a		
Pr ¹⁴⁸	80s*	386,000	28s	a			
Pr ¹⁴⁹	30s*	572,000	9s	a			
Pr ¹⁵⁰	15s*	596,000	4s	a			

Nuclide	$T_{1/2}$	Max Mc/MT	Time at Max.	Mc/MT at 1 hr.	Mc/MT at 1 day	Mc/MT at 1 month	Mc/MT at 1 yr.
Pr ¹⁵¹	7s*	548,000	0	a			
Pr ¹⁵²	5s*	425,000	0	a			
Pr ¹⁵³	3s*	238,000	0	a			
Pr ¹⁵⁴	2s*	84,300	0	a			
Pr ¹⁵⁵ (P)	2s*	77,800	0	a			
Pr ¹⁵⁶ (P)	1.5s*	20,950	0	a			
Nd ¹⁴⁷	11.6d	54.0	31.2m-2.40h	54.0	51.0	8.99	a
Nd ¹⁴⁹	1.7h	4,160	3.15-4.62m	2,840	0.27	a	
Nd ¹⁵¹	12m	11,340	41s	373	a		
Nd ¹⁵²	3m*	23,250	19s	0.0248	a		
Nd ¹⁵³	18s*	84,000	4s	a			
Nd ¹⁵⁴	12s*	51,000	1-2s	a			
Nd ¹⁵⁵	5s*	44,000	0	a			
Nd ¹⁵⁶	4.5s*	14,250	0	a			
Nd ¹⁵⁷	3s*	6,240	0	a			
Nd ¹⁵⁸ (P)	2s*	5,920	0	a			
Nd ¹⁵⁹ (P)	1.5s*	1,000	0	a			
Pm ¹⁴⁷	3.7y	0.445	66.4-97.3d	0	0.027	0.386	0.386

Nuclide	T _{1/2}	Max Mc/MT	Time at Max.	Mc/MT at 1 hr.	Mc/MT at 1 day	Mc/MT at 1 month	Mc/MT at 1 yr.
Pm ¹⁴⁹	47h	136.1	7.56h	51.0	113.0	0.00424	a
Pm ¹⁵⁰	2.7h	40.0	0	30.45	0.864	a	
Pm ¹⁵¹	27.5h	91.3	1.64h	89.1	52.4	a	
Pm ¹⁵²	1h*	1,362	14.5m	834	0.000151	a	
Pm ¹⁵³	9m*	4,750	1.47m	551	a		
Pm ¹⁵⁴	3m*	6,300	41s	0.00837	a		
Pm ¹⁵⁵	60s*	6,510	13s	a			
Pm ¹⁵⁶	25s*	6,050	6s	a			
Pm ¹⁵⁷	13s*	4,425	1-2s	a			
Pm ¹⁵⁸	6s*	3,400	0	a			
Pm ¹⁵⁹	3.5s*	1,192	0	a			
Pm ¹⁶⁰	2.5s*	380.5	0	a			
Pm ^{161(P)}	2s*	140.5	0	a			
Sm ¹⁵¹	73y	0.00405	9.82-208d	7.1x10 ⁻⁵	0.00181	0.00405	0.00403
Sm ¹⁵³	47h	17.4	1.12h	17.3	12.51	0.000438	a
Sm ¹⁵⁵	25m	346.0	4.62m	78.3	a		
Sm ¹⁵⁶	10h	8.40	4.62m	7.80	1.62	a	
Sm ¹⁵⁷	2m*	807	41s	1.56x10 ⁻⁶	a		

Nuclide	$T_{1/2}$	Max Mc/MT	Time at Max.	Mc/MT at 1 hr.	Mc/MT at 1 day	Mc/MT at 1 month	Mc/MT at 1 yr.
Sm ¹⁵⁸	15m*	48.1	41s	3.105	a		
Sm ¹⁵⁹	14s*	670	3s	a			
Sm ¹⁶⁰	15s*	2,025	2-3s	a			
Sm ¹⁶¹	4s*	1,730	0	a			
Eu ¹⁵⁵	2y	0.00950	5.16-23.8h	0.00756	0.00950	0.00926	0.00681
Eu ¹⁵⁶	15.4d	0.2165	2.13d	0.02617	0.1903	0.0637	a
Eu ¹⁵⁷	15.4m	110.2	6.77m	11.31	a		
Eu ¹⁵⁸	1h	9.76	31.2m	8.80	1.11×10^{-6}	a	
Eu ¹⁵⁹	5m	56.5	1m	0.0230	a		
Eu ¹⁶⁰	70s*	61.6	28s	a			
Eu ¹⁶¹	22s*	45.1	9s	a			
Gd ¹⁵⁹	18h	0.310	45.8m	0.308	0.127	a	
Gd ¹⁶¹	3.6m	5.96	1.47m	7.7×10^{-5}	a		
Tb ¹⁶¹	6.8d	0.00286	31.2m-1.64h	0.00286	0.00259	0.000136	a

NOTE: Half-lives are those from ref. 3 although more recent data are shown in Part I.

(P) Indicates estimates made from Present's values.

APPENDIX A Part II - Continued

The following nuclides (4, 5) which are not included above (nor in ref. 3) are listed to indicate more recent or more complete information.

Nuclide	$T_{1/2}$	Remarks
Ge ^{72m}	0.3 μ s	essentially part of Ga ⁷² decay (~1%)
Ge ^{73m}	0.53s	" " " Ga ⁷³ " (100%)
Se ^{77m}	17.5s	2% decay of As ⁷⁷
Se ^{79m}	3.9m	100% decay of As ⁷⁹
Se ⁷⁹	$\leq 6 \times 10^4$ y	100% decay of As ⁷⁹
Kr ^{87m}	inst.	essentially decay of Br ⁸⁷ (2%)
Rb ^{85m}	0.9 μ s	" " " Rb ^{85m}
Rb ⁸⁷	5×10^{10} y	essentially stable, decay of Kr ⁸⁷
Y ^{89m}	16.1s	decay of Sr ⁸⁹ (0.02%)
Zr ⁹³	1.1×10^6 y	essentially stable, decay of Y ⁹³ (?)
Nb ^{93m}	~10y	decay of Y ⁹³ (?)
Rh ^{103m}	57m	decay of Ru ¹⁰³ (100%)
Pd ¹⁰⁷	7.5×10^6 y	essentially stable, decay of Rh ¹⁰⁷ (100%)
Ag ^{111m}	76s	decay of Pd ¹¹¹ (partial, ?%)
Cd ^{111m}	48.6m	" " Ag ¹¹¹ (9%)
Cd ^{117m}	2.72h	" " Ag ¹¹⁷ (100%)
In ¹¹⁵	6×10^{14} y	essentially stable
In ^{117m}	1.95h	decay of Cd ¹¹⁷ , Cd ^{117m} (partial, ?%)
Sn ^{117m}	14d	" " In ¹¹⁷ (0.03%)
I ¹²⁹	1.72×10^7 y	essentially stable, decay of Te ¹²⁹ (100%)
Xe ^{137m}	inst.	" decay of I ¹³⁷ (6.8%)
Cs ^{135m}	2.8×10^{-10} s	" " " Xe ¹³⁵ (97%)

Nuclide	$T_{1/2}$	Remarks
Cs ¹³⁵	$3.0 \times 10^6 \text{ y}$	essentially stable, decay of Xe ¹³⁵ (3%) Cs ^{135m} (97%)
Nd ¹⁴⁴	$\sim 2 \times 10^{15} \text{ y}$	essentially stable, decay of Pr ¹⁴⁴ (100%)
Sm ¹⁴⁷	$1.3 \times 10^{11} \text{ y}$	" " , decay of Pm ¹⁴⁷ (100%)
Eu ^{153m}	$1.4 \times 10^{-10} \text{ s}$	" decay of Sm ¹⁵³ (partial, ?%)

APPENDIX B - Nuclear Data for Possible Nuclides
Produced in Air

I. Nuclear Properties

The following data have been extracted from references 4, 5, 22, and 26 - 28. Possible reactions have been considered, although in some cases insufficient data are available and are therefore not shown here. Many possible nuclides may obviously be produced in extremely small amounts, if at all. Cross-sections (cs) are for thermal neutron capture reactions unless otherwise indicated.

1. Hydrogen: H^3 . $T = 12.26y$. H^2 , $cs = 5.7 \times 10^{-4}b$. H^2 0.015% of natural H and 0.000015% by volume of air. (β , 0.0180 Mev; no γ).
 $H^3 \rightarrow He^3$ (stable).

2. Carbon:

a. C^{14} . $T = 5.6 \times 10^3y$. C^{13} , $cs = 0.0007b$; N^{14} (n, p). $cs = 1.75b$. (β , 0.1561 Mev; no γ). C^{13} 1.11% of natural C and 0.0001% of air by weight. N^{14} 99.635% of natural N and 75.80% of air by weight. $C^{14} \rightarrow N^{14}$ (stable).

b. C^{15} . $T = 2.3s$. C^{14} , $cs < 10^{-6}$; N^{15} (n, p). C^{14} present in natural air in minute amounts. N^{15} 0.365% of natural N and about 0.249% of air by weight. (β , 80% 4.3 Mev, 20% 9.8 Mev; γ , 5.3 Mev).

3. Nitrogen:

a. N^{16} . $T = 7.36s$. N^{15} , $cs = 2.4 \times 10^{-5}b$; O^{16} (n, p). N^{15} 0.365% of natural N and about 0.249% of air by weight. (β , ~20% 10.3 Mev, ~40% 4.3 Mev, ~40% 3.8 Mev; γ , 6.13, 7.10 Mev). $N^{16} \rightarrow O^{16}$ (stable).

b. N^{17} . $T = 4.14s$. O^{17} (n, p), O^{17} 0.037% of natural O and about 0.009% of air by weight. (β , 3.7 Mev). $N^{17} \rightarrow O^{17}$ (stable).

4. Oxygen: O^{19} . $T = 29.4s$. O^{18} , $cs = 2.1 \times 10^{-4}b$. O^{18} 0.204% of natural O and about 0.05% of air by weight. (β , 70% 2.9 Mev, 30% 4.5 Mev; γ , 0.200, 1.37, 0.112 Mev). $O^{19} \rightarrow F^{19}$ (stable).

5. Neon: Ne^{23} . $T = 40.2s$. Ne^{22} 8.82% of natural Ne but only a trace in air, about 0.00013% by volume. (β , ~70% 4.40 Mev, ~29% 3.95 Mev, ~1% 2.4 Mev; γ , 0.44, 1.65 Mev). $Ne^{23} \rightarrow Na^{23}$ (stable).

6. Argon:

a. A^{37} . $T = 34.1d$. A^{36} , $cs = 6b$. A^{36} 0.34% of natural A and only a trace in air. (orb. elec. capture; no γ). $A^{37} \rightarrow Cl^{37}$ (stable).

b. A^{39} . $T = 2.6 \times 10^2y$. A^{38} , $cs = 0.8b$. A^{38} 0.06% of natural A and only a trace in air. (β , 0.56 Mev; no γ). $A^{39} \rightarrow K^{39}$ (stable).

6. Argon (continued)

c. A^{41} . $T = 1.83h$. A^{40} , $cs = 0.53b$. A^{40} 99.60% of natural A and about 1% of air by weight. (β , 99.1% 1.20 Mev, 0.9% 2.50 Mev; γ , 99.1% 1.30 Mev). $A^{41} \rightarrow K^{41}$ (stable).

7. Krypton (only a trace in air, about 0.00005%).

a. Kr^{79} . $T = 34.5h$. Kr^{78} , $cs = 2.0b$. Kr^{78} 0.354% of natural Kr. (91% orb. elec. capture; 9% β^+ , 0.598, 0.32 Mev; γ , 0.044, 0.263 Mev, 13 others). $Kr^{79} \rightarrow Br^{79}$ (stable).

b. Kr^{81} . $T = 2.1 \times 10^5 y$. Kr^{80} , $cs = 95$. Kr^{80} 2.27% of natural Kr. (orb. electron capture). $Kr^{81} \rightarrow Br^{81}$ (stable).

c. Kr^{85m} . $T = 4.4h$. Kr^{84} , $cs = 0.1b$. Kr^{84} 56.90% of natural Kr. (77% β , 0.825 Mev; γ , 0.150 Mev; 23% IT; γ , 0.305 Mev). (also a fission product).

d. Kr^{85} . $T = 10.60y$. Kr^{84} , $cs = 0.06b$. Kr^{84} 56.90% of natural Kr. (β , 99.4% 0.670 Mev, 0.6% 0.15 Mev). (See Kr^{85m} for decay). (also a fission product).

e. Kr^{87} . $T = 78m$. Kr^{86} , $cs = 0.06b$. Kr^{86} 17.37% of natural Kr. (β , ~65% 3.6 Mev, ~35% 2 others; γ , 0.40, 2.6, 0.85, 2 others?). (also a fission product). $Kr^{87} \rightarrow Rb^{87} \rightarrow Sr^{87}$ (stable).

8. Rubidium (also fission products).

a. Rb^{85m} . $T = 0.9\mu s$. Decay of Kr^{85} . (IT; orb. elect. capture; γ , 0.513 Mev).

b. Rb^{87} . $T = 5 \times 10^{10} y$. Decay of Kr^{87} . (Natural isotope of Rb, 27.85%). (β , 0.275 Mev, no γ).

9. Iodine: I^{125} . $T = 60.0d$. Decay of Xe^{125} . (Orb. elect. capture; γ , 0.035 Mev).

10. Xenon (only a trace in air, 0.000006% by volume).

a. Xe^{125} . $T = 18h$. Xe^{124} . Xe^{124} 0.096% of natural Xe. (Orb. elec. capture; γ , 0.055, 0.187, 0.243 Mev). $Xe^{125} \rightarrow I^{125} \rightarrow Te^{125}$ (stable).

10. Xenon (continued)

b. Xe^{127} . $T = 36.4\text{d}$. Xe^{126} . Xe^{126} 0.090% of natural Xe. (orb. elec. capture; γ , 0.057, 0.145, 0.170, 2.00, 0.365 Mev). $\text{Xe}^{127} \xrightarrow{\epsilon} \text{I}^{127}$ (stable).

c. Xe^{133} . $T = 5.270\text{d}$. Xe^{132} , $cs = 0.2b$. Xe^{132} 26.89% of natural Xe. (β , 0.345 Mev; γ , 0.081 Mev). (also a fission product).
 $\text{Xe}^{133} \xrightarrow{\quad} \text{Cs}^{133}$ (stable).

d. Xe^{135} . $T = 9.2\text{h}$. Xe^{134} , $cs = 0.2b$. Xe^{134} 10.44% of natural Xe. (β , 97% 0.905 Mev, ~3% 0.55 Mev; γ , 0.60, 0.36 Mev). (also a fission product).

e. Xe^{137} . $T = 3.8\text{m}$. Xe^{136} , $cs = 0.15b$. Xe^{136} 8.87% of natural Xe. (β , 3.5 Mev; γ). (also a fission product).

11. Cesium (decay of Xe) (also fission products).

a. $\text{Cs}^{135\text{m}}$. $T = 2.8 \times 10^{-10} \text{s}$. (IT; γ , 0.248 Mev) (see Xe^{135}).

b. Cs^{135} . $T = 3.0 \times 10^6 \text{y}$. (β , 0.21 Mev, no γ) (see Xe^{135}).

c. Cs^{137} . $T = 27\text{y}$. (β , 92% 0.523 Mev, 8% 1.19 Mev). (see Xe^{137}).

12. Barium (decay of Xe, Cs) (also a fission product).

$\text{Ba}^{137\text{m}}$. $T = 2.60\text{m}$. (IT; 0.6612 Mev) (see Xe^{137}).

APPENDIX B - continued

II. Estimates of Radioactivities Produced in Air.

The following tables show estimates of induced radioactivities in air following nuclear detonations. Radioactivities less than one curie per megaton (fission or fusion) are indicated by the letter "a". Except for N^{14} (n, p) reactions estimates were based on (n, γ) reactions of thermal neutrons. It was assumed that 10^{26} neutrons/MT were captured in air (in addition to those captured by N^{14} (n, p)). A method similar to that of Heiman (25) was used here, the results of which are shown below. While insufficient data are available for more accurate estimates, it is believed that these give some indication of the significance of induced nuclides in air. The estimates are based on air burst. Although induced nuclides of Ne, Kr, Rb, I, Xe, Cs, Ba, and possibly others would probably be found in air, preliminary estimates indicate that their concentrations are too low to produce significant radioactivity levels. Since the estimates shown below are based on atmospheric dry air at sea level, actual levels of the nuclides shown are probably much less than these values. This reduction may be compensated for at least in part by other impurities in the air in specific areas, however.

Nuclide	$T_{1/2}$	Mc/MT				
		0	1 hour	1 day	1 month	1 year
H^3	12.26y	a				
C^{14} *	5600y	0.034	0.034	0.034	0.034	0.034
N^{16}	7.36s	175	a			
O^{19}	29.4s	55	a			
A^{37}	34.1d	75.5	75.5	74.7	40.8	0.035
A^{39}	~260y	5.97×10^{-5}	5.97×10^{-5}	5.97×10^{-5}	5.97×10^{-5}	5.97×10^{-5}
A^{41}	1.83h	7760	5350	0.75	a	

Notes: *Estimated from ref. 22, includes N^{14} (n, p) C^{14} reactions.

Estimates of Activities in Air at Zero Time

Stable Nuclide	Atoms/cc in Air	Cross-Section (b)	Product Nuclide	Rel. No. Atoms	% Product Atoms	Actual No. Atoms	Activity Mc/MT
N ¹⁴	4.8x10 ¹⁹	0.10	N ¹⁵	4.18x10 ⁻⁶	85.34	8.54x10 ²⁵	stable
N ¹⁵	1.406x10 ¹⁷	2.4x10 ⁻⁵	N ¹⁶	3.37x10 ⁻¹²	0.0007	6.88x10 ¹⁹	175
O ¹⁶	1.123x10 ¹⁹	10 ⁻⁴ (est.)	O ¹⁷	1.1x10 ⁻⁹	0.0225	2.22x10 ²²	stable
O ¹⁷	3.90x10 ¹⁵	0.5	O ¹⁸	1.95x10 ⁻¹⁰	0.004	3.98x10 ²¹	stable
O ¹⁸	2.01x10 ¹⁶	2.1x10 ⁻⁴	O ¹⁹	4.2x10 ⁻¹²	0.0008	8.57x10 ¹⁹	55
A ³⁶	9.66x10 ¹⁶	6	A ³⁷	5.8x10 ⁻⁷	11.84	1.18x10 ²⁵	75.5
A ³⁸	1.58x10 ¹³	0.8	A ³⁹	1.27x10 ⁻⁹	0.026	2.59x10 ²²	5.97x10 ⁻⁵
A ⁴⁰	2.55x10 ¹⁷	0.53	A ⁴¹	1.35x10 ⁻⁷	2.76	2.76x10 ²⁴	7,760
C ¹²	7.94x10 ¹⁶	0.0033	C ¹³	2.62x10 ⁻¹⁰	0.0054	5.34x10 ²¹	stable
C ¹³	7.89x10 ¹⁴	7x10 ⁻⁴	C ¹⁴	5.5x10 ⁻¹⁵	1.13x10 ⁻⁷	1.12x10 ¹⁷	a
TOTALS				4.898x10 ⁻⁶	100	10 ²⁶	

Note: N¹⁴ (n, p) C¹⁴ reactions are not included here.

APPENDIX C - Nuclear Data for Possible
Nuclides Induced in Soil

I. Nuclear Data

The following nuclear data for nuclides possibly induced in soils following nuclear detonations have been extracted from references 4, 5 and 29. Since soils vary greatly in composition from one locale to another, it is obvious that some nuclides may be produced which are not included here. Many of the nuclides shown below are not usually present in sufficient quantities to be of significant interest to this study, however. Unless otherwise indicated, all reaction cross sections (cs) are for thermal (n, γ) reactions. Decay is by β emission unless otherwise shown.

1. Lithium (natural Li 92.5% Li^7 , soils probably contain less than 0.01% Li). Li^8 . $T = 0.86\text{s}$. $cs = 0.033\text{b}$. (β , ~90% 13 Mev; γ , ~10% 5.2 Mev, others?).
 $\text{Li}^8 \xrightarrow{\alpha} \text{Be}^{8m} \xrightarrow{2\alpha} 2 \text{He}^4 \text{ (stable)}$
 $\text{Li}^8 \xrightarrow{\alpha} \text{Be}^{8m} \xrightarrow{5 \times 10^{-14} \text{s}} 2 \text{He}^4 \text{ (stable)}$

2. Beryllium: Be^{8m} . $T < 5 \times 10^{-14} \text{s}$. Decay of Li^8 . (2 α 's ~3 Mev, other levels).

3. Boron (natural B 81.3% B^{11} . Total B in soils probably 0.001% - 0.01%). B^{12} . $T = 0.0222\text{s}$. $\text{B}^{11} < 0.05\text{b}$. (β , ~98% 13.43 Mev, 1.7% 9.0 Mev, others?, γ , 1.7% 4.43 Mev). $\text{B}^{12} \rightarrow \text{C}^{12} \text{ (stable)}$.

4. Carbon (natural C 1.11% C^{13} , ~0.0088% of soil). C^{14} . $T = 5600\text{y}$. C^{13} , $cs = 0.0007\text{b}$, also N^{14} (n, p), $cs = 1.75\text{b}$. (see isotopes in air). (β , 0.1561 Mev; no γ). $\text{C}^{14} \rightarrow \text{N}^{14} \text{ (stable)}$.

5. Nitrogen (natural N 0.365% N^{15} , 99.635% N^{14} , few soils contain as much as 0.5% N). (see isotopes in air). N^{16} . $T = 7.36\text{s}$. $cs = 2.4 \times 10^{-5}\text{b}$.

6. Oxygen (natural O 0.214% O^{18} and ~1% of soils) (see isotopes in air). O^{19} . $T = 29.4\text{s}$. $cs = 2 \times 10^{-4}\text{b}$.

7. Sodium: (natural Na, 100% Na^{23} ; all soils contain $\geq 0.01\%$ Na, upper range of inhabited soils is ~2.5%) Na^{24} . $T = 15.0\text{h}$. Na^{23} , $cs = 0.6\text{b}$. (β , ~100% 1.390 Mev, 0.003% 4.17 Mev; γ , 1.368, 2.754, 4.0, 5.3 Mev).
 $\text{Na}^{24} \rightarrow \text{Mg}^{24} \text{ (stable)}$.

8. Magnesium (in soils usually < 1%). Mg^{27} . $T = 9.45 \text{m}$. Mg^{26} , $cs = 0.26\text{b}$. (β , 58% 1.75 Mev, 42% 1.59 Mev; γ , 58% 0.84 Mev, 41% 1.02 Mev) (Mg^{26} 11.29% of Mg).
 $\text{Mg}^{27} \rightarrow \text{Al}^{27} \text{ (stable)}$.

9. Aluminum (natural Al 100% Al^{27} ; all arable soils contain $\geq 0.2\%$, may be as high as 15% in some soils). Al^{28} . $T = 2.30 \text{m}$. Al^{27} , $cs = 0.23\text{b}$. (β , 2.87 Mev; γ , 1.78 Mev). $\text{Al}^{28} \rightarrow \text{Si}^{28} \text{ (stable)}$

10. Silicon. (natural Si 3.12% Si³⁰; in nearly all soils >10%, ranges from 20% to 50% usually). Si³¹. T = 2.62h. Si³⁰, cs = 0.1b. (β, 1.476 Mev; γ, 1.26 Mev (0.07%)). Si³¹ ----> p³¹ (stable).

11. Phosphorus. (natural P 100% P³¹). p³². T = 14.3d. p³¹, cs = 0.2b. (β, 1.708 Mev; no γ). p³² ----> s³² (stable).

12. Sulfur. (natural S, 4.215% S³⁴ 0.017% S³⁶; probably present in most soils much < 5%).

a. s³⁵. T = 87.1d. S³⁴, cs = 0.26b. (β, 0.167 Mev; no γ). s³⁵ ----> Cl³⁵ (stable).

b. s³⁷. T = 5.04m. S³⁶, cs = 0.14b. (β, ~10% 4.7 Mev, ~90% 1.6 Mev; γ, ~90% 3.1 Mev, others < 2 Mev (< 1%)). s³⁷ ----> Cl³⁷ (stable).

13. Chlorine. (natural Cl, 75.53% Cl³⁵, 24.47% Cl³⁷; probably < 0.01% of soil).

a. Cl³⁶. T = 3.2x10⁵y. Cl³⁵, cs = 42b. (98.3% β, 0.714 Mev; 1.7% orb. elec. capture; no γ). Cl³⁶ ~~98.3%~~ ----> A³⁶ (stable).

$$\begin{array}{c} e \\ 1.7\% \end{array} \rightarrow s^{36} \text{ (stable).}$$

b. Cl^{38m}. T = 1.0s. Cl³⁷, cs = 0.005b. (IT; γ, 0.66 Mev).

$$\begin{array}{c} IT \\ 1s \end{array} \rightarrow Cl^{38} \xrightarrow{37.5m} A^{38} \text{ (stable).}$$

c. Cl³⁸. T = 37.5m. Cl³⁷, cs = 0.56b. (β, 53% 4.81 Mev, 16% 2.77 Mev, 31% 1.1 Mev; γ, 1.60, 2.15 Mev). (see above).

14. Potassium. (natural K, 93.08% K³⁹, 6.91% K⁴¹; 0-3% in soil, average 1%).

a. K⁴⁰. T = 1.6x10⁹y. K³⁹, cs = 1.9b. (89% β, 1.35 Mev; 11% orb. elec. capture). K⁴⁰ ~~89%~~ ----> Ca⁴⁰ (stable).

$$\begin{array}{c} e \\ 11\% \end{array} \rightarrow A^{40} \text{ (stable).}$$

b. K⁴². T = 12.47y. K⁴¹, cs = 1.17b. (β, 82% 3.54 Mev, 18% 1.98 Mev; γ, ≥ 11% 1.53 Mev, 0.32 Mev). K⁴² ----> Ca⁴² (stable).

15. Calcium. (natural Ca, 96.96% Ca⁴⁰, 2.07% Ca⁴⁴, 0.0033% Ca⁴⁶; most soils much < 5% Ca).

a. Ca⁴¹. T = 2x10⁵y. Ca⁴⁰, cs = 0.22b. (orb. elec. capture; no γ).

$$Ca^{41} \xrightarrow{e} K^{41} \text{ (stable).}$$

b. Ca^{45} . $T = 152\text{d}$. Ca^{44} , $cs = 0.69\text{b}$. (β , 0.254 Mev). $\text{Ca}^{45} \rightarrow \text{Sc}^{45}$ (stable).

c. Ca^{47} . $T = 4.9\text{d}$. Ca^{46} , $cs = 0.25\text{b}$. (β , 80% 0.68 Mev , 20% 2.0 Mev ; γ , 1.31 , 0.48 , 0.83 Mev). $\text{Ca}^{47} \rightarrow \text{Sc}^{47} \rightarrow \text{Ti}^{47}$ (stable).

16. Scandium: Sc^{47} . $T = 3.43\text{d}$. Decay of Ca^{47} above. (β , $\sim 70\%$ 0.440 Mev , $\sim 30\%$ 0.610 Mev ; γ , $\sim 70\%$ 0.17 Mev).

17. Titanium. (natural Ti 5.25% Ti^{50} ; in most soils $\geq 0.5\%$, some areas may contain $10\text{-}30\%$ in surface soil).

a. Ti^{45} . $T = 3.10\text{h}$. Ti^{46} (n , $2N$) (β^+ , $\sim 83\%$ 1.00 Mev , $\sim 17\%$ orb. elec. capture; no γ). $\text{Ti}^{45} \xrightarrow{\beta^+} \text{Sc}^{45}$ (stable).

b. Ti^{51} . $T = 5.79\text{m}$. Ti^{50} , $cs = 0.14\text{b}$. (β , 2.13 , 1.50 Mev ; γ 0.323 , 0.93 , 0.60 Mev). $\text{Ti}^{51} \rightarrow \text{V}^{51}$ (stable).

18. Manganese. (natural Mn 100% Mn^{55} ; all soils contain $> 0.001\%$ and probably $> 0.01\%$, rarely $1\text{-}2\%$). Mn^{56} . $T = 2.58\text{h}$. Mn^{55} , $cs = 13.3\text{b}$. (β , 60% 2.86 Mev , 25% 1.05 Mev , 15% 0.75 Mev ; γ 0.845 (100%), 1.81 ($\sim 30\%$), 2.13 ($\sim 20\%$), 2.7 , 3.0 Mev). $\text{Mn}^{56} \rightarrow \text{Fe}^{56}$ (stable).

19. Iron. (from few tenths % to 10% in U.S., some areas of world $40\text{-}50\%$).

a. Fe^{55} . $T = 2.94\text{y}$. Fe^{54} , $cs = 2.3\text{b}$. (orb. elec. capture; no γ). $\text{Fe}^{55} \xrightarrow{e^-} \text{Mn}^{55}$ (stable).

b. Fe^{59} . $T = 45.1\text{d}$. Fe^{58} , $cs = 0.98\text{b}$. (β , 54% 0.462 Mev , 46% 0.271 Mev , 30% 1.56 Mev ; γ , 57% 1.100 Mev , 43% 1.290 Mev , 2.8% 0.191 Mev).

$\text{Fe}^{59} \rightarrow \text{Co}^{59}$ (stable).

20. Nickel. (natural Ni , 67.8% Ni^{58} , 3.66% Ni^{62} , 1.16% Ni^{64}) (probably $< 1\%$ in soils).

a. Ni^{57} . $T = 36.4\text{h}$. Ni^{58} (n , $2n$). (50% β^+ , 0.835 Mev ; γ , 1.38 Mev ; 50% orb. elec. capture; γ , 0.128 , 1.38 , 1.91 Mev , others).

$\text{Ni}^{57} \xrightarrow{\beta^+} \text{Co}^{57} \xrightarrow{e^-} \text{Fe}^{57}$ (stable).

b. Ni^{59} . $T = 8 \times 10^4\text{y}$. Ni^{58} , $cs = 4.2\text{b}$. (orb. elec. capture; no γ). $\text{Ni}^{59} \xrightarrow{e^-} \text{Co}^{59}$ (stable).

c. Ni^{63} . $T = 80\text{y}$. Ni^{62} , $cs = 15\text{b}$. (β , 0.063 Mev ; no γ). $\text{Ni}^{63} \rightarrow \text{Cu}^{63}$ (stable).

d. Ni⁶⁵. T = 2.56h. Ni⁶⁴, cs = 1.6b. (β , 57% 2.10 Mev, 29% 0.60 Mev, 14% 1.0 Mev; γ , 1.5, 1.12, 0.37 Mev). Ni⁶⁵ ----> Cu⁶⁵ (stable).

21. Copper. (natural Cu, 69.1% Cu⁶³, 30.9% Cu⁶⁵) (probably < 1% in soils).

a. Cu⁶². T = 9.80m. Cu⁶³ (n, 2n). (β^+ , 2.91 Mev; γ , 0.66, 0.86, 1.18, 2.24 Mev, others?) Cu⁶² $\xrightarrow{\beta^+}$ Ni⁶² (stable).

b. Cu⁶⁴. T = 12.82h. Cu⁶³, cs = 4.1b. (43% orb. elec. capture; γ , 0.5% 1.35 Mev; 19% β^+ , 0.657 Mev; 38% β^- , 0.571 Mev).

c. Cu⁶⁶. T = 5.15m. Cu⁶⁵, cs = 2.0b. (β , 91% 2.63 Mev, 9% 1.59 Mev; γ , 9% 1.044 Mev). Cu⁶⁶ ----> Zn⁶⁶ (stable).

22. Arsenic. (natural As 100% As⁷⁵; probably 0.02% or less in soils).
As⁷⁶. T = 26.6h. As⁷⁵, cs = 4.1b. (β , 50% 2.97 Mev, 32% 2.41 Mev, 15% 1.76 Mev, 3% 0.36 Mev; γ , 0.560, 0.64, 1.20, 1.40, 2.05, 1.8 Mev). As⁷⁶ ----> Se⁷⁶ (stable).

23. Iodine. (natural I 100% I¹²⁷; probably < 0.2% in soils). I¹²⁸. T = 24.98m. I¹²⁷, cs = 6.7b. (94% β , 76% 2.12 Mev, 16% 1.66 Mev, 2% 1.12 Mev; γ , 0.455, 0.54, 0.99 Mev; 6% orb. elec. capture; γ , 0.75 Mev).

APPENDIX C - continued

II. Radioactivities Induced in Soil.

The following tables show estimates of induced radioactivities in soil following nuclear detonations. Radioactivities less than one curie per megaton (fission or fusion) are indicated by the letter "a".

These estimates were based on (n, γ) reactions of thermal neutrons, using a method similar to that of Heiman (ref. 25, see Appendix B, II). For these estimates Nevada Test Site soil was used which does not appear to differ greatly from that which may be considered of "average" composition (see below). It was assumed that 10^{26} neutrons/MT were captured in soil.

These data can only indicate the most significant radioactivities which may be expected. Differences in soil composition would produce wide variations from the values shown here. Also, the conditions of detonation would determine neutron fluxes available for capture in soil.

Nuclide	Radioactivity in Soils (Mc/MT)				
	0	1 hour	1 day	1 month	1 year
Na ²⁴	1620	1430	542	a	a
Mg ²⁷	584	7.05	a		
Al ²⁸	83,870	15.9	a		
Si ³¹	991	773	1.78	a	
P ³²	1.21	1.21	1.15	0.276	a
K ⁴⁰	a				
K ⁴²	204.5	194	50.0	a	
Ca ⁴⁵	0.300	0.300	0.300	0.263	0.057
Ca ⁴⁹	1100	135	a		
Ti ⁵¹	156	0.0015	a		
Mn ⁵⁶	2122	1655	3.82	a	
Fe ⁵⁵	0.110	0.110	0.110	0.104	0.087
Fe ⁵⁹	0.014	0.014	0.014	0.0095	0.00006

Composition of the (NTS) Soil Assumed (29)

<u>Element</u>	<u>% by Wt.</u>	<u>Element</u>	<u>% by Wt.</u>
H	1.00	Si	28.40
C	0.80	P	0.10
O	50.16	K	2.50
Na	1.60	Ca	5.70
Mg	0.80	Ti	0.20
Al	6.80	Mn	0.04
		Fe	1.90

Density: 1.18g/cm³ (30).

The following is a comparison of the more or less anomalous elements in NTS soil with what may be a reasonable "average" soil, and with the range for all soils (except extreme anomalies) (29, 30).

<u>Element</u>	<u>% by Weight</u>		
	<u>NTS Soil</u>	<u>Range</u>	<u>"Average"</u>
Ca	5.7	0.5-10	4
Ti	0.2	0.1-2	0.6
K	2.5	0.1-3	1
Fe	1.9	0.2-12	3
I	0	< 0.2	0.1
S	0	< 5	0.1

APPENDIX D - Nuclear Data for Possible
Nuclides Induced in Sea Water

I. Nuclear Data.

The following nuclear data for nuclides possibly induced in sea water following nuclear detonations associated with the sea have been extracted from references 4, 5, 25, 31 and 32. Since many of the nuclides included are also found in other categories, references to nuclear data are made to other annexes as: Appendix B (air)*, Appendix A (fission products)***, and Appendix C (soils)****. Cross-sections (cs) refer to thermal neutron reactions. The percentages by weight of each element in sea water are shown in parentheses.

1. H^3 (*) (H 10.8%).
2. Li^8 (****) (Li $2 \times 10^{-5}\%$).
3. B^{12} (****) (B $4.8 \times 10^{-4}\%$).
4. C^{14} (*, ****) (C 0.0028%).
5. Nitrogen (*, ****) (N $5 \times 10^{-5}\%$); N^{16} , N^{17} .
6. O^{19} (*, ****) (O 85.70%).
7. F^{20} . T = 10.7s. F^{19} , cs = 0.009b. F^{19} 100% of natural F. (F $1.3 \times 10^{-4}\%$ of sea water) (β , 5.414 Mev; γ , 1.63 Mev). $F^{20} \rightarrow Ne^{20}$ (stable).
8. Ne^{23} (*) (Ne $3 \times 10^{-8}\%$). Ne^{22} , cs = 0.036b.
9. Na^{24} (****) (Na 1.05%).
10. Mg^{27} (****) (Mg 0.13%).
11. Al^{28} (****) (Al $10^{-6}\%$).
12. Si^{31} (****) (Si 0.0003%).
13. P^{32} (****) (P $7 \times 10^{-6}\%$).
14. Sulfur (****) (S 0.09%); S^{35} , S^{37} .
15. Chlorine (****) (Cl 1.90%); Cl^{36} , Cl^{38} , Cl^{38m} .
16. Argon (*) (A $6 \times 10^{-5}\%$); A^{37} , A^{39} , A^{41} .
17. Potassium (****) (K 0.380%); K^{40} , K^{42} .
18. Calcium (****) (Ca 0.400%); Ca^{41} , Ca^{45} , Ca^{49} .

19. Sc^{46m}. T = 19.5s. Sc⁴⁵, cs = 10b. Sc⁴⁵ 100% natural Sc. (Sc 4x10⁻⁹% of sea water) (IT; γ , 0.14 Mev). Sc^{46m} $\xrightarrow{\text{IT}}$ Sc⁴⁶ $\xrightarrow{\text{IT}}$ Ti⁴⁶ (stable).

20. Sc⁴⁶. T = 85d. (see Sc^{46m} above). (β , ~99% 0.36 Mev, 0.004% 1.48 Mev; γ , 1.12 Mev (~99%), 100% 0.89 Mev). (cs = 12b).

21. Titanium (****) (Ti 10⁻⁷%); Ti⁴⁵, Ti⁵¹.

22. Vanadium (natural V, 99.76% V⁵¹) (V, 2x10⁻⁷%).

a. V⁴⁹. T = 330d. Decay of Cr⁴⁹. (orb. elec. capture; no β ; no β^+ ; no γ). V⁴⁹ $\xrightarrow{e^-}$ Ti⁴⁹ (stable).

b. V⁵². T = 3.76m. V⁵¹, cs = 5.1b. (β , 2.6 Mev; γ , 1.44 Mev). V⁵² $\xrightarrow{\text{IT}}$ Cr⁵² (stable).

23. Chromium (natural Cr, 4.31% Cr⁵⁰) (Cr, 5x10⁻⁹%).

a. Cr⁴⁹. T = 41.9m. Cr⁵⁰ (n, 2n). (β^+ , 1.54, 1.39, 0.73 Mev; γ , 0.089, 0.063, 0.15 Mev). Cr⁴⁹ $\xrightarrow{\beta^+}$ V⁴⁹ $\xrightarrow{e^-}$ Ti⁴⁹ (stable).

b. Cr⁵¹. T = 27.8d. Cr⁵⁰, cs = 15.0b (orb. elec. capture; γ , 0.323 9.8%), 0.62 Mev). Cr⁵¹ $\xrightarrow{e^-}$ V⁵¹ (stable).

24. Manganese (****) (Mn 2x10⁻⁷%); Mn⁵⁴, Mn⁵⁶.

25. Iron (****) (Fe 10⁻⁶%); Fe⁵⁵, Fe⁵⁹.

26. Cobalt (natural Co 100% Co⁵⁹) (Co 5x10⁻⁸%).

a. Co⁵⁷. T = 270d. (orb. elec. capture; γ , 0.123, 0.137, 0.014 Mev). Co⁵⁷ $\xrightarrow{e^-}$ Fe⁵⁷ (stable). (also decay of Ni⁵⁷).

b. Co⁵⁸. T = 72d. Co⁵⁹ (n, 2n). (86% orb. elec. capture; 14% β^+ , 0.475 Mev; γ , 0.805, 1.62 Mev). Co⁵⁸ $\xrightarrow{\beta^+}$ Fe⁵⁸ (stable).

c. Co⁶⁰. T = 5.3y. Co⁵⁹, cs = 20b. Also decay of Co^{60m}. (β , 100% 0.309 Mev, 0.05% 1.48 Mev; γ , 1.1728, 1.3325 Mev). Co⁶⁰ $\xrightarrow{\text{IT}}$ Ni⁶⁰ (stable).

d. Co^{60m}. T = 10.5m. Co⁵⁹, cs = 16b. (99+% IT; γ , 0.0589 Mev; 0.3% β , 1.54 Mev; γ , 1.33 Mev).

27. Nickel (****) ($\text{Ni } 5 \times 10^{-8}\%$); Ni^{57} , Ni^{59} , Ni^{63} , Ni^{65} .

28. Copper (****) ($\text{Cu } 3 \times 10^{-7}\%$); Cu^{62} , Cu^{64} , Cu^{66} .

29. Zinc ($\text{Zn } 10^{-6}\%$ in sea water) (natural Zn, 48.8% Zn^{64} , 27.81% Zn^{66} , 4.11% Zn^{67} , 18.56% Zn^{68} , 0.62% Zn^{70}).

a. Zn^{65} . $T = 245\text{d}$. Zn^{64} , $cs = 0.40b$. (98% orb. elec. capture; γ , 46% 1.114 Mev, 52% no γ ; 2% β^+ , 0.325 Mev, 2% no γ). $\text{Zn}^{65} \xrightarrow{\beta^+} \text{Cu}^{65}$ (stable).

b. Zn^{69m} . $T = 13.8h$. Zn^{68} , $cs = 0.097b$. (IT; γ , 0.436 Mev).
 $\text{Zn}^{69m} \xrightarrow{\text{IT}} \text{Zn}^{69} \xrightarrow{\beta^-} \text{Ga}^{69}$ (stable).

c. Zn^{69} . $T = 52m$. Zn^{68} , $cs = 1.0b$. (β , 0.90 Mev; no γ). (see Zn^{69m}).

d. Zn^{71} . $T = 2.2m$. Zn^{70} , $cs = 0.09b$. (β , 2.4 Mev; γ , 0.12, 0.51, 0.90, 1.09 Mev). $\text{Zn}^{71} \xrightarrow{\beta^-} \text{Ga}^{71}$ (stable).

30. Gallium (***). ($\text{Ga } 5 \times 10^{-8}\%$). Ga^{68} , Ga^{70} , Ga^{72} .

31. Germanium ($10^{-8}\%$ of sea water) (natural Ge, 20.55% Ge^{70} , 27.37% Ge^{72} , 7.67% Ge^{73} , 36.74% Ge^{74} , 7.67% Ge^{76}).

a. Ge^{71} . $T = 12d$. Ge^{70} , $cs = 3.3b$. (orb. elec. capture). $\text{Ge}^{71} \xrightarrow{e^-} \text{Ga}^{71}$ (stable).

b. Ge^{75} . $T = 82m$. Ge^{74} , $cs = 0.55b$. (β , 85% 1.19 Mev, 11% 0.92 Mev, 3 others; γ , 0.264, 0.199 Mev, 4 others). (***). $\text{Ge}^{75} \xrightarrow{\beta^-} \text{As}^{75}$ (stable).

c. Ge^{77m} . $T = 52s$. Ge^{76} , $cs = 0.03b$. (β , 2.8 Mev; γ , 0.215 Mev; IT; γ , 0.159 Mev). (***).

d. Ge^{77} . $T = 12h$. Ge^{76} , $cs = 0.27b$. (β , 42% 2.2 Mev, 35% 1.38 Mev, 3 others?; γ , 0.26, 0.56 Mev, 22 others?). (see Ge^{77m}) (***).

32. As⁷⁶. (****) ($\text{As } 3 \times 10^{-7}\%$) (As^{75} 100% natural As).

33. As⁷⁷. (***). Decay of Ge^{77m} above.

34. Selenium. ($\text{Se } 4 \times 10^{-7}\%$ of sea water) (natural Se, 0.87% Se^{74} , 9.02% Se^{76} , 7.58% Se^{77} , 23.52% Se^{78} , 49.82% Se^{80} , 9.19% Se^{82}).

a. Se^{75} . $T = 127\text{d}$. Se^{74} , $cs = 26\text{b}$. (orb. elec. capture; γ , 0.265, 0.136, 0.280, 0.402, 7 others). $\text{Se}^{75} \xrightarrow{e^-} \text{As}^{75}$ (stable).

b. $\text{Se}^{77\text{m}}$. Decay of $\text{Ge}^{77\text{m}}$. (***)

c. $\text{Se}^{79\text{m}}$. (***) Se^{78} , $cs = 0.4\text{b}$.

d. Se^{79} . (***) Decay of $\text{Se}^{79\text{m}}$.

e. $\text{Se}^{81\text{m}}$. (***) Se^{80} , $cs = 0.03\text{b}$.

f. Se^{81} . (***) Se^{80} , $cs = 0.5\text{b}$.

g. $\text{Se}^{83\text{m}}$. (***) Se^{82} , $cs = 0.05\text{b}$.

h. Se^{83} . (***) Se^{82} , $cs = 0.004\text{b}$.

35. Bromine. ($6.5 \times 10^{-3}\%$ of sea water) (natural Br, 50.54% Br^{79} , 49.46% Br^{81}).

a. $\text{Br}^{80\text{m}}$. $T = 4.5\text{h}$. Br^{79} , $cs = 2.9\text{b}$. (IT; γ , 0.037 Mev, 0.049 Mev).
 $\text{Br}^{80\text{m}} \xrightarrow{\text{IT}} \text{Br}^{80} \xrightarrow{92\%} \text{Kr}^{80}$ (stable)
 $\quad \quad \quad \searrow \begin{smallmatrix} e^-/\beta^+ \\ 8\% \end{smallmatrix} \rightarrow \text{Se}^{80}$ (stable).

b. Br^{80} . $T = 8.5\text{m}$. Br^{79} , $cs = 8.5\text{b}$. (92% β , 78% 1.99 Mev, 14% 1.38 Mev; γ , 0.620 Mev; 5% orb. elec. capture; 3% β^+ , 0.86 Mev). (see $\text{Br}^{80\text{m}}$).

c. Br^{82} . $T = 35.9\text{h}$. Br^{81} , $cs = 3.1\text{b}$. (β , 0.444 Mev, others; γ , 0.77, 0.55, 0.62, 1.03, 1.31, 1.47, ~1.9 Mev, 2 others). $\text{Br}^{82} \xrightarrow{\quad} \text{Kr}^{82}$ (stable).

36. Krypton (*, ***) (Kr $3 \times 10^{-8}\%$ of sea water) (natural Kr, 0.354% Kr^{78} , 2.27% Kr^{80} , 56.90% Kr^{84} , 17.37% Kr^{86}); Kr^{79} , Kr^{81} , Kr^{85} , Kr^{87} .

37. Rubidium (Rb $1.2 \times 10^{-5}\%$) (natural Rb, 72.15% Rb^{85} , 27.85% Rb^{87} naturally radioactive).

a. Rb^{86} . $T = 18.6\text{d}$. Rb^{85} , $cs = 0.82\text{b}$. (β , 88% 1.76 Mev, ~10% 0.68 Mev; γ , ~10% 1.08 Mev). $\text{Rb}^{86} \xrightarrow{\quad} \text{Sr}^{86}$ (stable).

b. Rb^{88} . (***) Rb^{87} , $cs = 0.12\text{b}$.

38. Strontium. (Sr $8 \times 10^{-4}\%$) (natural Sr, 0.55% Sr^{84} , 9.87% Sr^{86} , 7.02% Sr^{87} , 82.56% Sr^{88}).

a. Sr^{85} . $T = 65\text{d}$. Sr^{84} , $cs = 1.0\text{b}$. (100% orb. elec. capture).
 $\text{Sr}^{85} \xrightarrow{e^-} \text{Rb}^{85}$ (stable).

b. Sr^{89} . (***) Sr^{88} , $cs = 0.005\text{b}$.

39. Molybdenum (***) ($\text{Mo } 10^{-6}\%$) (natural Mo, 15.86% Mo^{92} , 9.12% Mo^{94} , 15.70% Mo^{95} , 16.50% Mo^{96} , 9.45% Mo^{97} , 23.75% Mo^{98} , 9.62% Mo^{100}); Mo^{93} , Mo^{99} , Mo^{101} .

40. Silver (natural Ag, 51.35% Ag^{107} , 48.65% Ag^{109}). ($\text{Ag } 3 \times 10^{-8}\%$).

a. Ag^{106} . $T = 8.3\text{d}$. Ag^{107} (n, 2n). (orb. elec. capture; γ , 0.51, 1.53, 1.05 Mev, ~13 others). $\text{Ag}^{106} \xrightarrow{e} \text{Pd}^{106}$ (stable).

b. Ag^{108} . $T = 2.3\text{m}$. Ag^{107} , cs = 30b. (98.1% β , 97.3% 1.77 Mev, 0.8% 1.15 Mev; γ , 0.8% 0.62 Mev; 1.6% orb. elec. capture; γ , 0.44 Mev, 0.66 Mev; 0.14% β^+ , 0.78 Mev).

c. Ag^{110} . $T = 270\text{d}$. Ag^{109} , cs = 2.8b. (95% β , 58% 0.087 Mev, 0.53 Mev, others; γ , 0.657 Mev, ~14 others; 5% IT; γ , 0.116 Mev).

d. $\text{Ag}^{110\text{m}}$. $T = 24.2\text{s}$. Ag^{109} , cs = 110b. (β , ~60% 2.24 Mev, ~40% 2.82 Mev; γ , 0.66, 0.94 Mev, others). (see Ag^{110}).

41. Cadmium. ($\text{Cd } 5.5 \times 10^{-9}\%$) (natural Cd, 1.21% Cd^{106} , 0.88% Cd^{108} , 12.39% Cd^{110} , 28.86% Cd^{114} , 7.58% Cd^{116}).

a. Cd^{107} . $T = 6.7\text{h}$. Cd^{106} , cs = 1.0b. (99.7% orb. elec. capture; γ , 4.0% 0.846 Mev; 0.3% β^+ , 0.32 Mev). $\text{Cd}^{107} \xrightarrow{\beta^+} \text{Ag}^{107}$ (stable).

b. Cd^{109} . $T = 1.30\text{y}$. Cd^{108} . (orb. elec. capture). $\text{Cd}^{109} \xrightarrow{e} \text{Ag}^{109}$ (stable).

c. $\text{Cd}^{115\text{m}}$. (***) Cd^{114} , cs = 0.14b.

d. Cd^{115} . (***) Cd^{114} , cs = 1.1b.

e. $\text{Cd}^{117\text{m}}$. (***) Cd^{116} , cs = 1.5b.

42. Indium. ($\text{In } < 2 \times 10^{-6}\%$) (natural In, 4.23% In^{113} , 95.77% In^{115} (radioactive)).

a. $\text{In}^{113\text{m}}$. $T = 1.75\text{h}$. Decay of Sn^{113} . (IT; γ , 0.392 Mev).

b. $\text{In}^{114\text{m}}$. $T = 49\text{d}$. In^{113} , cs = 56b. (96.5% IT; γ , 0.192 Mev; 3.5% orb. elec. capture; γ , 0.722, 0.556 Mev).

c. In^{114} . $T = 72\text{s}$. In^{113} , $cs = 2\text{b}$. (98% β , 1.98, 0.68 Mev; 2% orb. elec. capture; 0.004% β^+ , 0.40 Mev) (see In^{114m}).

d. In^{115} . (***). (natural, radioactive).

e. In^{116m} . $T = 54.20\text{m}$. In^{115} , $cs = 145\text{b}$. (β , 51% 1.00 Mev, 28% 0.87 Mev, 21% 0.60 Mev; γ , 1.274 Mev, ~5 others).

$\text{In}^{116m} \rightarrow \text{Sn}^{116} \text{ (stable)}$

f. In^{116} . $T = 13\text{s}$. In^{115} , $cs = 52\text{b}$. (β , 2.9 Mev; no γ).

$\text{In}^{116} \rightarrow \text{Sn}^{116} \text{ (stable)}$.

43. Tin . ($\text{Sn } 3 \times 10^{-7}\%$) (natural Sn, 0.95% Sn^{112} , 32.97% Sn^{120} , 4.71% Sn^{122} , 5.98% Sn^{124}).

a. Sn^{113} . $T = 112\text{d}$. Sn^{112} , $cs = 1.3\text{b}$. (orb. elec. capture; γ , 0.393 Mev). $\text{Sn}^{113} \xrightarrow{e^-} \text{In}^{113m} \xrightarrow{\text{IT}} \text{In}^{113} \text{ (stable)}$.

b. Sn^{121m} . $T = > 5\text{y}$. Sn^{120} , $cs = 0.001\text{b}$. (β , 0.42 Mev).

$\text{Sn}^{121m} \rightarrow \text{Sb}^{121} \text{ (stable)}$.

c. Sn^{121} . (***). Sn^{120} , $cs = 0.14\text{b}$.

d. Sn^{123m} . $T = 131\text{d}$. Sn^{122} , $cs = 0.001\text{b}$. (β , 142 Mev; no γ).

$\text{Sn}^{123m} \rightarrow \text{Sb}^{123} \text{ (stable)}$.

e. Sn^{123} . (***). Sn^{122} , $cs = 0.16\text{b}$.

f. Sn^{125m} . $T = 9.5\text{m}$. Sn^{124} , $cs = 0.2\text{b}$. (β , 0.51, 2.06, 1.17, Mev; γ , 0.33, 0.64, 1.07, 1.39 Mev).

g. Sn^{125} . (***). Sn^{124} , $cs = 0.004\text{b}$.

44. Antimony. ($Sb < 5 \times 10^{-8}\%$) (natural Sb, 57.25% Sb^{121} , 42.75% Sb^{123}). (***).

a. Sb^{122} . $T = 2.80d$. Sb^{121} , $cs = 6.0b$. (97% β , 1.45, 1.98, 0.74 Mev; 3% orb. elec. capture; β^+ ?; γ , 0.56 Mev, 3 others). $Sb^{122} \rightarrow Te^{122}$ (stable).

b. Sb^{124a} . $T = 21m$. Sb^{123} , $cs = 0.03b$. (IT; γ , 0.018 Mev; β , ~2.5 Mev).

c. Sb^{124b} . $T = 1.3m$. Sb^{123} , $cs = 0.03b$. (IT; γ , 0.012 Mev; β , 3.2 Mev). (see Sb^{124a}).

d. Sb^{124} . $T = 60d$. Sb^{123} , $cs = 2.5b$. (β , 0.61, 2.37 Mev, others; γ , 0.60 Mev, others). (see Sb^{124a}).

45. Tellurium. Te^{125m} . $T = 58d$. Decay of Sn^{125} . (IT; γ , 0.110, 0.0354 Mev).

46. Iodine. I^{128} . (****) ($I 5 \times 10^{-6}\%$).

47. Xenon. (*, ***). ($Xe 10^{-8}\%$).

48. Cesium. ($Cs 5 \times 10^{-8}\%$) (natural Cs 100% Cs^{133}).

a. Cs^{134m} . $T = 3.2h$. Cs^{133} , $cs = 0.017b$. (~99% IT; γ , 0.127, 0.010, 0.137 Mev; ~1% β , 0.55 Mev).

b. Cs^{134} . $T = 2.3y$. Cs^{133} , $cs = 26b$. (β , ~70% 0.65 Mev, ~30% 3 others; γ , 0.605, 0.797 Mev, 11 others). (see Cs^{134m}).

49. Barium. (***). ($Ba 6.2 \times 10^{-7}\%$) Ba^{131} , Ba^{133m} , Ba^{133} , Ba^{139} .

50. Lanthanum. (***). ($La 3 \times 10^{-8}\%$) (natural La, 99.911% La^{139} , 0.089% La^{138} (radioactive)).

a. La^{137} . $T = \sim 6 \times 10^4 y$. Decay of Ce^{137} . (orb. elec. capture).

b. La^{140} . La^{139} , $cs = 8.1b$.

51. Cerium. ($\text{Ce } 4 \times 10^{-8}\%$) (natural Ce, 0.193% Ce^{136} , 0.25% Ce^{138} , 88.48% Ce^{140} , 11.07% Ce^{142}).

a. $\text{Ce}^{137\text{m}}$. $T = 35\text{h}$. Ce^{136} , $cs = 0.6\text{b}$. (IT ; 0.255 Mev).

$\text{Ce}^{137\text{m}} \xrightarrow{\text{IT}} \text{Ce}^{137} \xrightarrow{e} \text{La}^{137} \xrightarrow{e} \text{Ba}^{137} \text{ (stable)}.$

b. Ce^{137} . $T = 8.7\text{h}$. Ce^{136} , $cs = 6.3\text{b}$. (orb. elec. capture; γ , 3% 0.445 Mev, 100% 0.010 Mev) (see $\text{Ce}^{137\text{m}}$).

c. $\text{Ce}^{139\text{m}}$. $T = 55\text{s}$. Ce^{138} , $cs = 0.007\text{b}$. (IT ; γ , 0.740 Mev).

$\text{Ce}^{139\text{m}} \xrightarrow{\text{IT}} \text{Ce}^{139} \xrightarrow{e} \text{La}^{139} \text{ (stable)}.$

d. Ce^{139} . $T = 140\text{d}$. Ce^{138} , $cs \sim 1\text{b}$. (orb. elec. capture; γ , 0.166 Mev) (see $\text{Ce}^{139\text{m}}$).

e. Ce^{141} . (***) . Ce^{140} , $cs = 0.31\text{b}$.

f. Ce^{143} . (***) . Ce^{142} , $cs = 1.0\text{b}$.

52. Tungsten (natural W, 26.4% W^{182} , 30.6% W^{184} , 28.4% W^{186}) ($\text{W } 10^{-8}\%$).

a. W^{180} . $T \sim 3 \times 10^{14}\text{y}$. Decay of Ta^{180} . (α , 3.2 Mev). (found in nature).

b. W^{181} . $T = 140\text{d}$. W^{182} (n , $2n$). (orb. elec. capture). $\text{W}^{181} \xrightarrow{e} \text{Ta}^{181} \text{ (stable)}.$

c. $\text{W}^{182\text{m}}$. $T = 1.3 \times 10^{-9}\text{s}$. Decay of Ta^{182} (partial). (IT ; γ , 0.1001 Mev).

d. W^{185} . $T = 74\text{d}$. W^{184} , $cs = 2.0\text{b}$; W^{186} (n , $2n$) (β , 0.430 Mev; γ , 0.132? others?). $\text{W}^{185} \xrightarrow{e} \text{Re}^{185} \text{ (stable)}.$

e. W^{187} . $T = 24.00\text{h}$. W^{186} , $cs = 34\text{b}$. (β , 80% 0.62 Mev, 20% 1.30 Mev; γ , 0.072, 0.134, 0.480, 0.619, 0.686, 0.77 Mev, 8 others?).

$\text{W}^{187} \xrightarrow{e} \text{Re}^{187\text{m}} \xrightarrow{\text{IT}} \text{Re}^{187} \xrightarrow{3 \times 10^{10}\text{y}} \text{Os}^{187} \text{ (stable)}.$

53. Rhenium:

a. $\text{Re}^{187\text{m}}$. $T = 0.54\mu\text{s}$. Decay of W^{187} . (IT ; γ , 0.133 Mev).

b. Re^{187} . $T = 5 \times 10^{10}\text{y}$. Decay of $\text{Re}^{187\text{m}}$. (β , ≤ 0.008 Mev). (found in nature).

54. Gold (natural Au, 100% Au^{197}) ($\text{Au } 4 \times 10^{-10}\%$).

a. Au¹⁹⁸. $T = 2.70d$. Au^{197} , $cs = 98b$. (β , 99% 0.959 Mev, 0.98% 0.282 Mev, 0.02% 1.371 Mev; γ , 99% 0.41177 Mev, 0.8% 0.676 Mev, 0.2% 1.089 Mev). $Au^{198} \xrightarrow{\quad} Hg^{198}$ (stable).

b. Au¹⁹⁶. $T = 5.6d$. Au^{197} (n, 2n) Au^{196} . ($\sim 5\%$ β , 0.27 Mev; $\sim 95\%$ orb. elec. capture; γ , 0.426 Mev). $Au^{196} \xrightarrow{e^-} Pt^{196}$ (stable)
 $\searrow$
 Hg^{196} (stable)

55. Mercury (natural Hg, 0.146% Hg^{196} , 10.02% Hg^{198} , 29.8% Hg^{202} , 6.85% Hg^{204}) (Hg $3 \times 10^{-9}\%$).

a. Hg¹⁹⁷. $T = 65h$. Hg^{198} (n, 2n) (orb. elec. capture; γ , 99% 0.077 Mev, 1% 0.192 Mev). $Hg^{197} \xrightarrow{e^-} Au^{197}$ (stable).

b. Hg²⁰³. $T = 45.8d$. Hg^{202} , $cs = 3.8b$; Hg^{204} (n, 2n). (β , 0.210 Mev; γ , 0.279 Mev). $Hg^{203} \xrightarrow{\quad} Tl^{203}$ (stable).

56. Thallium. (natural Tl, 29.50% Tl^{203} , 70.50% Tl^{205} ($Tl < 10^{-9}\%$)).

a. Tl²⁰². $T = 12.0d$. Tl^{203} (n, 2n). (orb. elec. capture: γ , 0.439 Mev). $Tl^{202} \xrightarrow{e^-} Hg^{202}$ (stable).

b. Tl²⁰⁴. $T = 3y$. Tl^{203} , $cs = 11.0b$, Tl^{205} (n, 2n). ($\sim 2\%$ orb. elec. capture; $\sim 98\%$ β , 0.765 Mev; γ , 0.38 Mev). $Tl^{204} \xrightarrow{e^-} Pb^{204}$ (stable)
 $\xrightarrow{\sim 2\% e^-} Hg^{204}$ (stable)

c. Tl²⁰⁶. $T = 4.20m$. Tl^{205} , $cs = 0.10b$. (β , 1.51 Mev; no γ).
 $Tl^{206} \xrightarrow{\quad} Pb^{206}$ (stable).

57. Lead. (natural Pb, 1.5% Pb^{204} , 23.6% Pb^{206} , 52.3% Pb^{208}) (Pb $3 \times 10^{-7}\%$).

a. Pb²⁰³. $T = 52h$. Pb^{204} (n, 2n). (orb. elec. capture; γ , 0.279, 0.400, 0.685 Mev). $Pb^{203} \xrightarrow{e^-} Tl^{203}$ (stable).

b. Pb²⁰⁵. $T = \sim 5 \times 10^7 y$. Pb^{204} , $cs = 0.8b$; Pb^{206} (n, 2n). (orb. elec. capture). $Pb^{205} \xrightarrow{e^-} Tl^{205}$ (stable).

c. Pb²⁰⁹. $T = 3.32h$. Pb^{208} , $cs = 0.0006b$. (β , 0.635 Mev; no γ).
 $Pb^{209} \xrightarrow{\quad} Bi^{209} \xrightarrow[\sim 2 \times 10^{17} y]{\alpha} Tl^{205}$ (stable).

58. Bismuth (natural Bi, 100% Bi^{209}) (Bi $2 \times 10^{-8}\%$).

a. Bi²⁰⁹. $T = \sim 2 \times 10^{17} y$. Decay of Pb^{209} . (α , ~ 3 Mev) (natural Bi).

$\text{Bi}^{209} \xrightarrow{\alpha} \text{Tl}^{205} \text{ (stable)}.$

b. Bi^{201m} . $T = 5d$. Bi^{209} , $cs = 0.019b$. ($99\% \beta$, 1.170 Mev ; $2 \times 10^{-4}\%$ α , 4.77 Mev ; no γ). $\text{Bi}^{210m} \xrightarrow{99\% \alpha} \text{Po}^{210} \xrightarrow{\alpha} \text{Pb}^{206} \text{ (stable)}$

$\text{Po}^{210} \xrightarrow{\alpha} \text{Tl}^{206} \xrightarrow{\alpha} \text{Pb}^{206} \text{ (stable)}$

c. Bi^{210} . $T = 2.6 \times 10^6 y$. Bi^{209} , $cs = 0.013b$. (α , 4.94 Mev ; $\sim 0.4\% \beta$).

$\text{Bi}^{210} \xrightarrow{\alpha} \text{Tl}^{206} \xrightarrow{\alpha} \text{Pb}^{206} \text{ (stable)}$

$\text{Po}^{210} \xrightarrow{\alpha} \text{Pb}^{206} \text{ (stable)}$

59. Emanation. (Radon) ($Em \ 9 \times 10^{-18}\%$, radioactive).

60. Radium. ($Ra \ 3 \times 10^{-14}\%$, radioactive).

61. Thorium. ($Th \ 7 \times 10^{-8}\%$) (natural $Th \ 100\% \ Th^{232}$, radioactive). Th^{233} .
 $T = 23.5h$, $cs = 7.40b$. (β , 1.23 Mev ; no γ).

$\text{Th}^{233} \xrightarrow{\alpha} \text{Neptunium Series}.$

62. Protactinium. ($Pa \ 3 \times 10^{-7}\%$) (natural $Pa \ 100\% \ Pa^{231}$, radioactive).

Pa^{232} . $T = 1.32d$. $cs = 200b$. (β , $90\% \ 0.3 \text{ Mev}$, $8\% \ 0.5 \text{ Mev}$, $2\% \ 1.27 \text{ Mev}$; γ , 0.047 , 0.109 , 0.455 , 0.82 , 0.97 Mev , 10 others).

$\text{Pa}^{232} \xrightarrow{\alpha} \text{Th}^{232} \rightarrow \text{Thorium Series}.$

Note: Em (Rn) and Ra are not present in sufficient quantities to be of interest here.

APPENDIX D - continued

II. Radioactivities Induced in Sea Water

The following are estimates of neutron-induced radioactivities in sea water at various times after a nuclear underwater detonation. Only thermal (n, γ) reactions were considered. Some activities would undoubtedly result from fast neutron reactions, although insufficient data are available for obtaining reasonable estimates. The thermal neutron reactions would probably produce most of the induced radioactivity, however.

The estimates shown below were made using a method similar to that of Heiman (25), assuming a total of 10^{26} neutrons available for capture in sea water. The neutron flux available and the induced activity would be determined by weapon design, depth of water above and below the weapon. The following can only give an indication of potentially important induced nuclides. Stable nuclides and nuclides whose estimated activities at zero time are less than 1 curie/MT are omitted. Activities at later times less than 1 curie/MT are indicated by the letter (a).

Nuclide	T	Radioactivities in Sea Water (Mc/MT)				
		0	1 hour	1 day	1 month	1 year
Li ⁸	0.86s	107.4	a			
B ¹²	0.022s	85,000	a			
N ¹⁶	7.36s	4.18×10^{-5}	a			
O ¹⁹	29.4s	73.2	a			
F ²⁰	10.7s	6.05	a			
Ne ²³	40.2s	0.00011	a			
Na ²⁴	15.0h	480	456	159	a	
Mg ²⁷	9.45m	27.6	3.27	a		
Al ²⁸	2.3m	6.56	a			
Si ³¹	2.65h	0.0038	0.00299	a		
P ³²	14.3d	0.000407	0.000407	0.000381	0.00004	a
S ³⁵	87.1d	0.0408	0.0408	0.0404	0.0323	0.00215
S ³⁷	5.04m	0.0209	a			

Nuclide	T	Radioactivities in Sea Water (Mc/MT)				
		0	1 hour	1 day	1 month	1 year
Cl ³⁶	3.2x10 ⁵ y	0.00019	0.00019	0.00019	0.00019	0.00019
Cl ^{38m}	1.0s	66,100	a			
Cl ³⁸	37.5m	3,320	1,102	a		
A ³⁷	34.1d	1.23x10 ⁻⁵	1.23x10 ⁻⁵	1.23x10 ⁻⁵	6.75x10 ⁻⁶	a
A ⁴¹	1.83h	1.06	0.705	a		
K ⁴²	12.47h	17.7	16.7	4.58	a	
Ca ⁴⁵	164d	0.0097	0.0097	0.0096	0.0068	0.0002
Ca ⁴⁷	4.9d	0.00018	0.00018	0.00016	a	
Sc ^{46m}	19.5s	0.048	a			
V ⁵²	3.76m	0.934	a			
Mn ⁵⁶	2.58h	0.00556	0.00427	a		
Co ^{60m}	10.5m	0.0134	0.000238	a		
Cu ⁶⁴	12.82h	0.000312	0.000293	0.00008	a	
Cu ⁶⁶	5.15m	0.0098	a			
Zn ⁶⁹	13.8h	0.00928	0.00892	0.00278	a	
Zn ⁷¹	2.2m	6.43x10 ⁻⁵	a			
Ga ⁷⁰	21m	0.000626	0.00008	a		
Ga ⁷²	14.20h	1.61x10 ⁻⁵	1.49x10 ⁻⁵	2.6x10 ⁻⁶	a	
Ge ^{77m}	72s	6.16x10 ⁻⁶	a			
Se ^{79m}	3.90m	0.00219	a			
Se ^{81m}	56.8m	2.33x10 ⁻⁵	1.17x10 ⁻⁵	a		
Se ⁸¹	18.2m	0.00121	0.00012	a		
Se ^{83m}	67s	0.000353	a			

Nuclide	T	Radioactivities in Sea Water (Mc/MT)				
		0	1 hour	1 day	1 month	1 year
Br ^{80m}	4.5m	7.92	0.000664	a		
Br ⁸⁰	18.5m	337	35.4	a		
Br ⁸²	35.9h	1.01	0.99	0.635	a	
Rb ⁸⁶	18.6d	5.54×10^{-5}	5.54×10^{-5}	5.43×10^{-5}	1.84×10^{-5}	a
Rb ⁸⁸	17.8m	0.00460	0.00437	a		
Mo ⁹⁹	67h	4.72×10^{-6}	4.72×10^{-6}	3.73×10^{-6}	a	
Mo ¹⁰¹	14.6m	0.000234	0.000013	a		
Ag ¹⁰⁸	2.3m	0.0334	a			
Ag ^{110m}	24.2s	0.643	a			
In ^{114m}	49d	1.05×10^{-5}	1.05×10^{-5}	1.04×10^{-5}	6.88×10^{-6}	a
In ¹¹⁴	72s	0.0220	a			
In ^{116m}	54.2m	0.0131	0.00609	a		
In ¹¹⁶	13s	70.0	a			
Sn ¹²³	40.0m	8.98×10^{-6}	3.14×10^{-6}	a		
Sn ¹²⁵	9.5m	5.4×10^{-5}	a			
Sb ¹²²	2.80d	7.59×10^{-5}	7.59×10^{-5}	5.91×10^{-5}	a	
Ba ¹³⁹	85m	0.000402	0.000250	a		
La ¹⁴⁰	40.20h	1.28×10^{-5}	1.27×10^{-5}	8.45×10^{-6}	a	
W ¹⁸⁷	24.0h	6.38×10^{-6}	5.54×10^{-6}	3.19×10^{-6}	a	
Th ²³³	23.5m	0.00177	0.000301	a		
Pa ²³²	1.32d	0.0238	0.0234	0.0143	a	

APPENDIX E - Biological Data

I. Absorption and Retention Data.

The following biological data have been extracted from reference 1 for nuclides of interest in this study. No data are available for some elements of interest, however. Only soluble compounds of the elements listed have been considered.

Some possible long-term effects of radioactive fallout are: (a) genetic effects, (b) shortening of life span, (c) leukemia, and (d) bone cancer. These effects continue to be investigated and have been recently reviewed by Dunham (24). It is also important to note the lack of available experimental information concerning the effects of small chronic doses of radiation.

Symbols

f₁ - fraction going from GI tract to blood

f_w - fraction taken orally that arrives in critical organ

f_a - fraction inhaled that is retained in critical organ

T_b - biological half life

- indicates no data given in reference 1.

Element	Total Body			Critical Organ				
	f ₁	f _a	T _b (days)	1st Choice	f _w	f _a	T _b (days)	2nd Choice
H	1.0	0.75	19	Total Body	1.0	0.75	19	-
Li	1.0	-	4	" "	1.0	-	4	-
Be	0.01	0.25	123	Bone	0.004	0.09	400	Spleen
B	-	-	-	-	-	-	-	-
C	0.95	0.72	230	Fat	0.5	0.36	35	Bone
N	-	-	-	-	-	-	-	-
O	-	-	-	-	-	-	-	-

Element	Total Body			Critical Organ				
	fi	fa	Tb (days)	1st Choice	fw	fa	Tb (days)	2nd Choice
F	1.0	0.75	1.08	Bone	0.1	0.08	140	Teeth
Ne	-	-	-	Total Body	-	-	-	-
Na	0.95	0.73	19	" "	0.95	0.73	19	-
Mg	-	-	-	-	-	-	-	-
Al	-	-	-	-	-	-	-	-
Si	-	-	-	-	-	-	-	-
P	0.7	0.60	13	Bone	0.2	0.2	1600	-
S	0.56	0.53	-	Skin	0.08	0.074	22	-
Cl	0.95	0.73	19	Total Body	0.95	0.73	19	-
A	-	-	-	" "	-	-	-	-
K	0.9	0.70	38	Muscle	0.7	0.53	37	-
Ca	0.9	0.70	18000	Bone	0.25	0.41	18000	-
Sc	0.0005	0.25	28	Spleen	2×10^{-5}	8×10^{-3}	15	Liver
Ti	-	-	-	-	-	-	-	-
V	0.005	0.25	42	Bone	0.0005	0.025	50	-
Cr	0.05	0.27	16	Kidneys	0.0007	0.004	110	-
Mn	0.1	0.3	2.6	"	0.004	0.02	2.5	Liver
Fe	0.8	0.65	-	Blood	0.8	0.65	65	-
Co	0.2	0.35	21	Liver	0.004	0.007	8.4	Spleen
Ni	0.2	0.35	-	"	0.004	0.007	8	-
Cu	0.28	0.39	-	"	0.09	0.13	39	Eyes

Element	Total Body			Critical Organ				
	fl	fa	Tb (days)	1st Choice	fw	fa	Tb (days)	2nd Choice
Zn	0.1	0.35	-	Bone	0.02	0.05	23	-
Ga	0.001	0.25	5	Bone	0.0004	0.1	3000	-
Ge	0.01	0.25	2	Kidneys	0.0002	0.005	6	-
As	0.03	0.26	280	"	0.0004	0.003	37	Bone
Se	-	-	23	"	*	*	3	-
Br	-	-	-	-	-	-	-	-
Kr	-	-	-	Total Body	-	-	-	-
Rb	1.0	0.75	13	Muscle	0.42	0.33	13	-
Sr	0.6	0.55	190	Bone	0.25	0.22	4000	-
Y	0.0005	0.25	550	"	0.0003	0.14	> 500	Lungs
Zr	0.0005	-	5000	"	0.0001	0.058	180	-
Nb	0.45	0.47	73	"	0.13	0.12	50	-
Mo	0.7	0.6	-	Bone	0.0002	0.0002	150	-
Tc	0.5	0.5	0.8	Kidneys	0.003	0.003	4	-
Ru	< 0.0005	0.25	86	"	0.00002	0.01	20	-
Rh	0.2	0.35	18	"	0.01	0.02	28	-
Pd	0.2	0.35	5	"	0.02	0.04	6	-
Ag	0.02	0.26	2	Liver	0.0001	0.002	3	-
Cd	0.0025	0.25	260	"	0.002	0.19	100	-
In	-	-	24	-	**	**	-	-
Sn	0.0087	0.25	67	Bone	0.0026	0.076	72	Lungs
Sb	0.03	-	370	"	0.0003	-	5	-

Element	Total Body			Critical Organ				
	f _l	f _a	T _b (days)	1st Choice	f _w	f _a	T _b (days)	2nd Choice
Te	0.25	0.37	1700	Kidneys	0.0007	0.02	15	-
I	1.0	0.75	130	Thyroid	0.2	0.15	120	-
Xe	-	-	-	Total Body	-	-	-	-
Cs	1.0	0.75	25	Muscle	0.48	0.36	17	-
Ba	0.1	0.35	120	Bone	0.07	0.2	~200	-
La	0.003	0.25	23	"	0.001	0.1	35	-
Ce	0.0005	0.25	330	"	0.0002	0.1	500	-
Pr	0.005	0.25	420	"	0.001	0.063	50	-
Nd	0.0005	-	47	"	***	***	35	-
Pm	0.0005	0.25	48	"	0.0002	0.09	100	-
Sm	0.0001	0.25	5	"	0.00003	0.05	40000	Spleen
Eu	0.0005	0.25	360	"	0.0002	0.09	1400	"
Gd	-	-	-	-	-	-	-	-
Tb	-	-	340	Bone	****	****	170	-
Ta	0.0005	-	150	Liver	0.0002	0.075	130	Lungs
W	0.1	-	-	Bone	0.008	0.024	5	-
Re	0.5	0.5	7	Thyroid	0.001	0.001	0.5	Skin
Au	0.1	0.30	12	Kidneys	0.024	0.072	50	Liver
Hg	-	-	-	"	-	-	-	-
Tl	0.45	-	-	Muscle	0.24	0.26	17	-
Pb	0.15	0.32	-	Bone	0.05	0.098	< 730	-
Bi	-	-	3	Liver	***	***	-	Kidneys

Element	Total Body			Critical Organ				
	F1	fa	Tb (days)	1st Choice	fw	fa	TB (days)	2nd Choice
Po	0.03	0.26	100	Spleen	0.0006	0.004	57	Lungs
U	0.0005	0.25	-	Kidneys	0.0002	0.08	30	Bone
Np	0.0005	-	42	Bone	0.0002	-	100	-
Pu	0.0001	0.25	-	"	0.0001	0.18	43000	Lungs

*Se - 0.03 fraction going from blood to critical organ.

** In - 0.02 " " " " " " " "

*** Nd and Bi - 0.35 fraction going from blood to critical organ.

**** Tb - 0.6 fraction going from blood to critical organ.

NOTE: The ICRP values are presently under revision and may continue to be revised as new data are accumulated. It may be noted that the biological half-life of Cs has been found to be longer than shown here. Future data may indicate considerable changes in the values shown here.

APPENDIX E - continued

II. Maximum Permissible Total Body Burdens.

The following table shows the maximum permissible total body burdens of nuclides of interest to this study where available. These data have been extracted from reference 1 and reference to it should be made for details of application and meaning associated with the MPC's listed. (See note above).

Nuclide	Critical Organ	MPC (μ c) Total Body Burden	MPC (μ c) GI Tract (from water)	MPC (μ c) GI Tract (from air)
H ³	Total	10 ⁴	10 ⁴	10 ⁴
C ¹⁴	Fat	260	5x10 ³	260
Na ²⁴	Total	15	15	8
P ³²	Bone	10	40	10
S ³⁵	Skin	300	360	300
Cl ³⁶	Total	230	580	770
A ⁴¹	Total	33	-	-
K ⁴²	Muscle	21	6	6
Ca ⁴⁵	Bone	14	3000	5000
Sc ⁴⁶	Spleen	6	0.006	7
Sc ⁴⁶	Liver	5		
Cr ⁵¹	Kidneys	600	17	240
Mn ⁵⁶	Kidneys	25	0.4	3
Mn ⁵⁶	Liver	8		
Fe ⁵⁵	Blood	1000	2x10 ⁴	3x10 ⁴
Fe ⁵⁹	Blood	13	390	320
Co ⁶⁰	Liver	3	0.06	0.2
Ni ⁵⁹	Liver	42	0.6	1

Nuclide	Critical Organ	MPC (μ c) Total Body Burden	MPC (μ c) GI Tract (from water)	MPC (μ c) GI Tract (from air)
Cu ⁶⁴	Liver	120	10	22
Zn ⁶⁵	Bone	400	13	80
Ga ⁷²	Bone	3	5×10^{-4}	0.3
As ⁷⁶	Kidneys	11	0.01	0.2
Sr ⁸⁹	Bone	2	20	10
Sr ⁹⁰ - Y ⁹⁰	Bone	1	1000	1000
Y ⁹¹	Bone	3	0.02	17
Zr ⁹⁵ - Nb ⁹⁵	Bone	10	0.02	12
Nb ⁹⁵	Bone	44	44	62
Mo ⁹⁹	Bone	17	0.01	0.01
Ru ¹⁰⁶ - Rh ¹⁰⁶	Kidneys	4	4×10^{-3}	3
Rh ¹⁰⁵	Kidneys	9	0.02	0.9
Ag ¹¹¹	Liver	39	4×10^{-3}	0.1
Cd ¹⁰⁹ - Ag ^{109m}	Liver	45	450	6×10^{-4}
Sn ¹¹³	Bone	84	0.8	42
Te ¹²⁷	Kidneys	4	0.09	4
Te ¹²⁹	Kidneys	1.4	0.03	1.4
I ¹³¹	Thyroid	0.6	> 0.6	
Xe ¹³³	Total	320		
Xe ¹³⁵	Total	100		
Cs ¹³⁷ - Ba ^{137m}	Muscle	98	98	98
Ba ¹⁴⁰ - La ¹⁴⁰	Bone	1	0.7	3
La ¹⁴⁰	Bone	7	7×10^{-3}	0.9

Nuclide	Critical Organ	MPC (μ c) Total Body Burden	MPC (μ c) GI Tract (from water)	MPC (μ c) GI Tract (from air)
Ce ¹⁴⁴ , Pr ¹⁴⁴	Bone	1	0.01	10
Pr ¹⁴³	Bone	6	0.04	3
Pm ¹⁴⁷	Bone	25	0.3	250
Sm ¹⁵¹	Bone	90	14	3×10^4
Ta ¹⁸²	Liver	6	0.03	27
W ¹⁸¹	Bone	24	0.2	0.5
Au ¹⁹⁶	Liver	8	0.3	16
Au ¹⁹⁶	Kidneys	32		
Au ¹⁹⁸	Liver	3	0.05	1.5
Au ¹⁹⁸	Kidneys	10		
Tl ²⁰²	Muscle	230	58	100
Tl ²⁰⁴	Muscle	200	25	50
Pb ²⁰³	Bone	61	1	4
Po ²¹⁰ (sol.)	Spleen	0.04	4×10^{-3}	0.04
Po ²¹⁰ (insol.)	Lungs	0.02		
U-nat.(sol.)	Kidneys	0.04	8×10^{-4}	0.4
U-nat.(insol.)	Lungs	0.01		
Pu ²³⁹ (sol.)	Bone	0.04	0.02	10
Pu ²³⁹ (insol.)	Lungs	0.02		
*Co ⁵⁷	Liver	15		
*Co ⁵⁸	Liver	1.3		
*W ¹⁸⁵	Bone	16		
*W ¹⁸⁷	Bone	4.8		

* Estimated using ref. 1.