sentially symmetric fission respectively. The peak widths at half-height are 14, 18.5 and 14 mass units. Since actual mass yields at peak maxima may be influenced by fine structure in these regions and light and heavy fragment curves may not be Gaussian in shape, the procedure for defining peak maxima was standardised by taking the mean of the mass-numbers corresponding to half of the maximum yields. In Table 3 comparable data are collected for other fissioning systems. The distribution of mass from ^{231}Pa fission does not fit in with the trend for the light peak in asymmetric fission to shift to lower masses with decreasing mass of the initially excited nucleus; the maximum is shifted about one or two mass-units towards heavier masses compared with 14 MeV neutron-induced fission of thorium [1] (initial compound nucleus ^{233}Th). The peak position is closer to those found for deuteron induced fission of thorium [12, 40] (initial compound nucleus, ^{234}Pa). These results are however in agreement with the trends predicted from data provided by TALÂT-ERBEN and GÜVEN [43].

Table 3. *Yield Parameters for the fission of various nuclides*

Fissioning system	Mass no. at maximum yield*		Asym./sym.	Peak width at half height	Reference
	Light peak	Heavy peak			
^{226}Ra + 11 MeV protons	88	136	1	15, 17, 15	8
^{232}Th + 14 MeV neutrons	91	138	5.2	12.5	1
^{232}Th + 9.5 MeV neutrons	93	137	6.7	15	40
^{232}Th + 13.6 MeV deuterons	92	137	4.6	12	12
^{231}Pa + 14 MeV neutrons	92	136	2.6	14, 18.5, 14	This work
^{235}U + 14 MeV neutrons	96	138	5.2	16	33
^{238}U + 14 MeV neutrons	98	138	9.4	14	19, 41
^{237}Np + 14 MeV neutrons	98	136	4.4	16	42

* Taken as the mean of the two mass-numbers corresponding to peak half-height. The sources of the data used are given in column 6.

The nucleus undergoing fission may be unusually heavy for neutron excited ^{231}Pa, a situation which could arise if the prompt neutrons were emitted late in the fission act, or if fission of the initial compound nucleus is enhanced relative to that of the residual nucleus remaining after the evaporation of one or more neutrons.

In the previous paper [1], an attempt was made to correlate the relative widths for exactly symmetric fission and for neutron re-emission with a term depending on the relative energies available for the two processes. In the case of protactinium, unfortunately, the necessary data are not available, and an exact comparison cannot be made; a rough calculation suggests that the ratio of neutron re-emission width to fission width would have to be about 7, and this value seems an improbable one.

Acknowledgement

This work has been carried out with the support of Extra Mural Research Contracts between the Atomic Energy Research Establishment, Harwell and the Universities of Durham and of Kent at Canterbury. Thanks are due to the Director A.E.R.E. for the loan of some 120 mg of protactinium and for permission for publication. One of us (M.G.B.) thanks the Councils of the Universities of Durham and of Kent at Canterbury for Research Awards supported by these contracts. We are grateful also for help provided by A.E.R.E., Harwell through the kindness of Mr. G.N. WALTON. In addition, we wish to record our gratitude to Mr. R. OLIVER who has been responsible for the operation of the accelerator.

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The Decay of ^{88}Nb

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With 8 figures. (Received January 12, 1966)

Summary

With deuteron and alpha bombardments on natural zirconium and yttrium targets respectively, the ^{88}Nb nuclide could be identified. The mass number was established by milking the daughter nuclide. The half-life of ^{88}Nb is 13.6 min and gamma lines of 75, 270, 400, 670, 1058 and 1080 keV are produced during its decay. These values agree with those found by KORTELING [1] but not with those of BUTEMENT and QUAIM [2]*. Relative intensities of the gamma lines and their coincidences have been studied. The 75 keV line was found to be appreciably converted. A possible decay scheme is presented and compared to those of ^{90}Zr and ^{86}Sr.

A 3.2 min half-life was found in the niobium fraction from a 100 MeV alpha bombardment on yttrium.

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Zusammenfassung Durch Deuteronen- und Alpha-Beschuß von natürlichen Zirkon- und Yttriumtargets konnte das Nuklid ^{88}Nb identifiziert werden. Die Massenzahl wurde festgestellt durch Abtrennen des Tochternuklids. Die Halbwertszeit von ^{88}Nb beträgt 13,6 min und Gammalinien von 75, 270, 400, 670, 1058 und 1080 keV werden beim Zerfall ausgesandt. Diese Werte stimmen überein mit den von KORTELING [1] gefundenen, aber nicht mit denen von BUTEMENT und QUAIM [2]. Ferner wurden die relativen Intensitäten der Gammalinien und deren Koinzidenzen untersucht. Bei der 75 keV-Linie wurde beträchtliche Konvertierung festgestellt.

Ein mögliches Zerfallsschema wird vorgeschlagen und mit denen von ^{90}Zr und ^{86}Sr verglichen.

Eine Halbwertszeit von 3,2 min wurde für die Niobfraktion nach einem 100 MeV Alpha-Beschuß von Yttrium festgestellt.

Résumé On a pu identifier le noyau ^{88}Nb dans les cibles de zirconium et d'yttrium bombardées par deutérons et par rayons α. Le nombre de masse a été déterminé après séparation du noyau dérivé. La période de ^{88}Nb est 13,6 min, il émet durant sa décroissance des rayons γ d'énergie 75, 270, 400, 670, 1058 et 1080 KeV. Ces valeurs sont celles trouvées par KORTELING [1] mais elles sont différentes de celles données par BUTEMENT et QUAIM [2]. On a étudié les intensités relatives des raies γ et leur coïncidence. On a trouvé que la ligne 75 KeV était notablement convertie. On indique un modèle possible pour la décroissance que l'on compare à celle des noyaux ^{90}Sr et ^{86}Sr.

En bombardant l'yttrium par des rayons α de 100 MeV on trouve dans la fraction radio-niobium un noyau de période 3,2 minutes.

1. Introduction

KORTELING found a half-life of about 15 min for a niobium isotope obtained with high energy proton bombardments. Its mass number was believed to be 88 and gamma lines of 80, 275, 395, 660 and 1040 keV were found to decay with the half-life. BUTEMENT and QUAIM [2] on the other hand reported a half-life of 21 min for ^{88}Nb, a maximum β^+ energy of 3.2 MeV, and gamma lines of 0.20, 0.72, 0.97 and 1.42 MeV. They prepared the nuclide bombarding niobium or molybdenum with 340 MeV protons. The half-life was established by direct counting and also by milking the ^{88}Zr daughter.

^{88}Zr, the daughter nuclide of ^{88}Nb, has two holes in the closed neutron shell of 50. It is to be expected that the level sequence of the excited states of ^{88}Zr resembles on one hand that of $^{90}_{40}\mathrm{Zr}_{50}$ (with the same number of protons and a magic number of neutrons), and on the other that of $^{86}_{38}\mathrm{Sr}_{48}$ (which has the 50–2 neutron configuration and where the 38 protons complete the 1f 5/2 subshell). Both ^{90}Zr and ^{86}Sr have been studied in detail [3, 4, 5, 6, 7]. The energy levels of ^{90}Zr and neighbouring nuclides have been explained successfully with a shell model analysis [8, 9].

2. Experimental

2.1 Target materials

Pure natural zirconium targets as a 20μ thick foil** were bombarded with deuterons of up to 50 MeV at 5 μA in the Karlsruhe cyclotron. In general, irradiations of 1 min were used. 99.9% pure yttrium, as Y_2O_3, was used for alpha bombardments at 100 MeV energy.

2.2 Measuring equipment

The β decay curves were taken with a methane flowcounter with a 1 mg/cm^2 thick mylar window. For gamma spectra a multichannel analyzer with a $3'' \times 3''$ or a $2'' \times 2''$ NaI(Tl) crystal was used. The distance from source to crystal was 10 cm. For higher resolutions, a germanium-lithium drifted solid state detector was used with a sensitive volume of 0.8 cm^3. The resolution was about 10 keV f.w.h.m. at 1 MeV energy.

Gamma-gamma coincidence measurements were made with a fast-slow coincidence circuit and two cylindrical $2'' \times 2''$ NaI(Tl) crystals. A 32×32 channel matrix was used. The resolving time of the circuit was about 20 nanoseconds.

Converted electrons were measured with a liquid nitrogen cooled silicon surface barrier detector, prepared in this laboratory [10]. The sensitive area was about 0.8 cm^2 with a depletion depth of about 2.7 mm. A half-width of about 5 keV could be obtained with this detector. Coincidences between converted electrons and gamma rays were obtained with the same detector and a scintillation counter with a $4'' \times 4''$ NaI(Tl) crystal, coupled to a multichannel analyzer. A 32×128 matrix was used. The resolving time of this coincidence circuit was about 1 μs.

2.3 Chemical procedures

The active parts of the zirconium targets, about 3 mg, were dissolved in concentrated HF and evaporated to dryness. The residue was dissolved in 10 N HCl–0.5 N HF and the carrier free niobium fraction was extracted with a 0.5% N-benzoyl-phenyl-hydroxyl-

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* We are informed by a private communication that Miss JOHANNA C. KAPTEYN, working independently from us at the Instituut voor Kernphysisch Onderzoek, Amsterdam, Netherlands, has observed ^{88}Nb in the niobium fraction isolated from proton irradiated zirconium and molybdenum. In this work the half-life was found to be about 13 min and gamma lines of 0.67 MeV and 1.07 MeV were observed to be due to this isotope together with annihilation radiation.

** Vakuumschmelze A.G., Hanau.

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amine solution in chloroform [11, 12]. The separated chloroform phase was washed twice with 10 N–0.5 N HF containing some zirconium carrier. The niobium solution was then placed on a filter paper and dried. With this procedure a sample could be ready for counting in about 10 min. For electron conversion measurements, a drop of the organic solution was placed on a 1 mg/cm^2 mylar film and evaporated.

For the yttrium irradiations, the same technique was applied after dissolving yttrium oxide in concentrated HCl. A sample could be counted 3.5 min after the end of the irradiation by omission of the washings of the chloroform phase.

When zirconium fractions were separated from niobium the same method was applied. The niobium complex with N-benzoyl-phenyl-hydroxylamine in chloroform was shaken at intervals with a 10 N HCl–0.5 N HF solution containing zirconium carrier. The zirconium fraction was then purified by shaking it twice with fresh N-benzoyl-phenyl-hydroxylamine-chloroform solution, after which the zirconium was precipitated as the hydroxide. Alternatively a small ion exchange column with Dowex 1-X8, 50–100 mesh, in the chloride form, was used. Niobium and zirconium were adsorbed from a concentrated hydrochloric acid solution and the zirconium washed out at intervals with 7 N HCl solution [13].

3. Results

3.1 Gamma measurements

Figs. 1, 2 and 3 are gamma spectra of the niobium fractions obtained by bombarding zirconium at energies of 50, 40 and 30 MeV respectively.

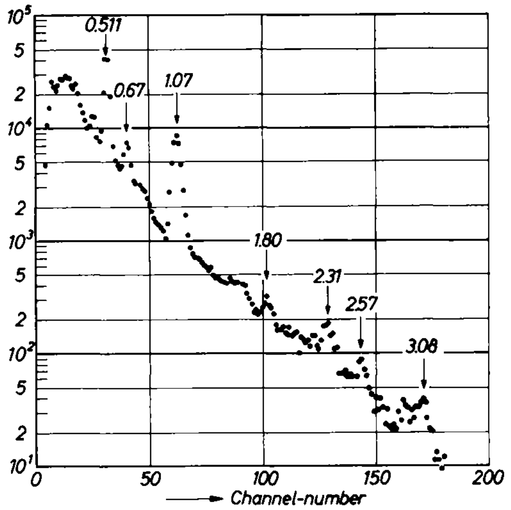

Fig. 1. Gamma spectrum of the niobium fraction from a 50 MeV deuteron bombardment on zirconium, taken 20 minutes after the end of irradiation

The most striking difference is seen in the 30 MeV irradiation where the prominent gamma rays of the spectra obtained with higher energy irradiations dissappear. 30 MeV is about the threshold for the (d, 4n) reaction [14].

The gamma lines at 0.075, 0.27, 0.40, 0.67, and 1.07 MeV in Figs. 1 and 2 all decay with a half-life between 12 and 15 min. Gamma rays with energies higher than 1.08 MeV do not decay with the short half-life. Fig. 4 shows a niobium spectrum from a deuteron irradiation at 40 MeV, about 2 hours after the end of irradiation. The peaks at 140 keV, 1.14 MeV and 2.31 MeV decay with the half-life of 14 hours of ^{90}Nb (^{90m}Zr). The peak at 906 keV, which grows in and decays with a longer half-life, may be attributed to ^{89m}Y, which decays with the ^{89}Zr half-life of 79 hours. The peaks at 3.5, 3.07 and 2.57 MeV decay with a half-life of 1.7 to 1.8 hours. The other unidentified peaks at 1.81, 1.61, 1.48 and 1.27 MeV decay possibly with the same half-life. Three days after the irradiation no unidentified

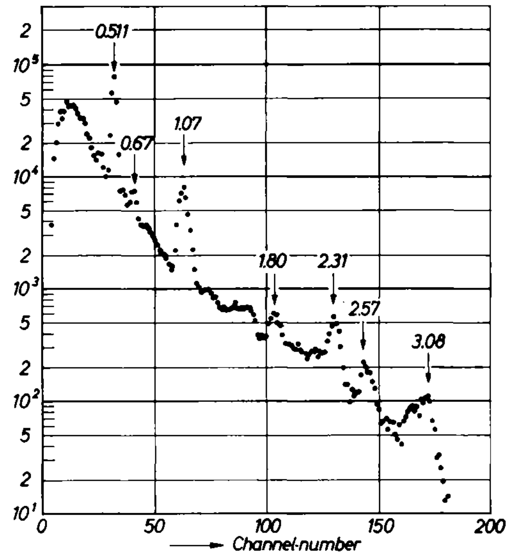

Fig. 2. Gamma spectrum of the niobium fraction from a 40 MeV deuteron bombardment on zirconium, taken 17 minutes after the end of irradiation

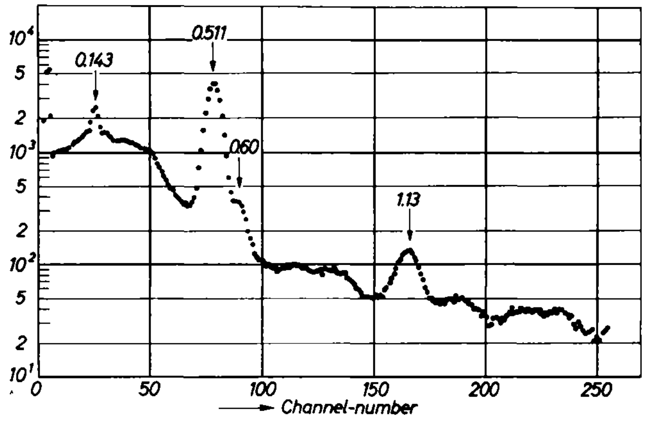

Fig. 3. Gamma spectrum of the niobium fraction from a 30 MeV deuteron bombardment on zirconium, taken 13 minutes after the end of irradiation

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peaks remain. No 1.7–1.8 h half-life is observed with a deuteron irradiation at 20 MeV, where the (d, 3n) process is practically excluded, and none of the corresponding gamma lines are seen in this case.

An analysis of the decay of the annihilation peak from a bombardment at 50 MeV is shown in Fig. 5, after substracting the 14 h component. It shows a composition of 13.7 min and 101 min.

The half-life of the short lived nuclide can be seen best from the decay of the gamma line at 1.07 MeV. This is represented in Fig. 6 from an irradiation at 50 MeV. A half-life of 13.6 min is obtained.

A gamma spectrum of the niobium fraction produced by bombarding yttrium with 100 MeV alpha particles shows the same lines for the short lived nuclide, with the corresponding half-life. No new gamma lines were detected, even when countings were started 5 min after the end of irradiation.

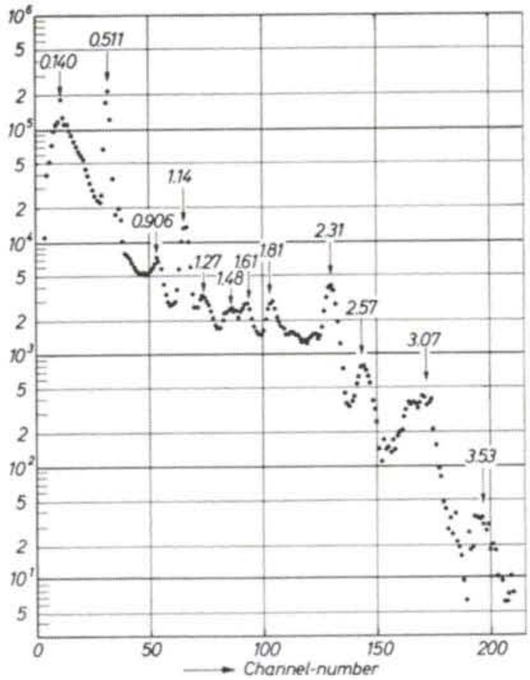

Fig. 4. Gamma spectrum of the niobium fraction from a 40 MeV deuteron bombardment on zirconium, taken 2.4 hours after the end of irradiation

3.2 Gamma-gamma coincidences and high resolution measurement

The gamma-gamma coincidence experiments revealed that the 1.07 MeV gamma was in coincidence with itself. In the singles spectra this line appeared with practically the half-width of a single line. The 1.07 MeV region was observed at higher resolution with the Ge-Li detector, where it could be seen that there are two gamma lines of equal intensities at 1.058 MeV and 1.080 MeV, both decaying with the short half-life. The other gamma lines belonging to the same nuclide were corroborated.

The coincidence experiments showed further that the "1.07 MeV peak" is in coincidence with the other gamma lines belonging to the short half-life. The 670 keV line is not in coincidence with the lines at 400 keV and 270 keV. These two last lines show coincidences between themselves. A reliable analysis of the coincidences of the 75 keV gamma line was not possible.

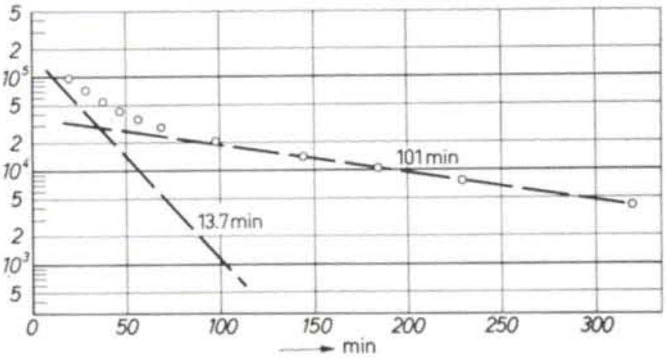

Fig. 5. Analysis of the decay of the 511 keV annihilation peak. The 14 hours tail has been substracted

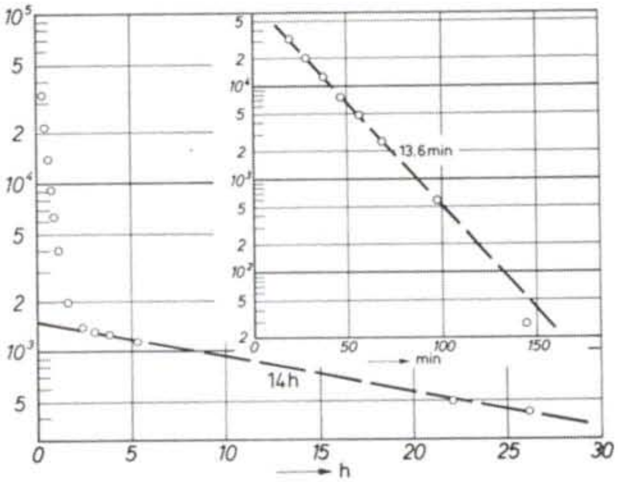

Fig. 6. Decay in activity of the 1.07 MeV + 1.14 MeV gamma lines (the last one belongs to ^{90}Nb)

3.3 Electron conversion and e.c. – gamma coincidence measurements

The electron conversion spectrum showed clearly the K and L + M converted electrons from the 75 keV line decaying with the short half-life. The other lines belonging to this nuclide were not appreciably converted. The K/L + M coefficient is estimated to be ≥ 3.3. An exact figure could not be derived because of uncertainties in the substraction of the background and because of an unknown contribution of the direct gamma ray to the L + M peak.

Coincidences of the K converted and L + M converted electrons of the 75 keV gamma transition showed that they are in coincidence with all other gamma lines belonging to the short lived nuclide.

Converted electrons from other nuclides which could be seen during these experiments corresponded to the 133 and 142 keV transitions which occur in the decay of 14 h ^{90}Nb, and the 594 keV M4 transition in ^{89m}Nb [15].

3.4 Results of flow counter measurements

The half-life of the short-lived nuclide is corroborated with measurements of the beta rays. With a deuteron irradiation at 50 MeV a half-life of 13.8 min is found for the shortest lived component, followed by about 2 hours, 14 hours and longer. At 40 MeV the short-lived component is weaker but still present. At 30 MeV the shortest half-life present is 105 min and at 20 MeV about 15 h. The time between the end of the irradiations and counting was about 15 min in these cases.

With quickly separated niobium samples from 100 MeV alpha irradiations on yttrium, a half-life of 3.2 min could be detected, in addition to 13.6 min, 106 min and 14 hours.

3.5 Interval separations of zirconium from niobium

To confirm the mass number of the 13.6 min niobium isotope a strong niobium sample, purified about 15 min after a 10 min deuteron irradiation at 50 MeV, was milked at 10 min intervals from its zirconium content. After some 40 days the zirconium fractions were measured with a multichannel analyzer. The integrated intensities of the gamma peaks at 395 keV (^{88}Zr) for the different fractions are shown in Fig. 7. Although there is some spreading in the points due to niobium adsorption, a half-life of 11–18 min corresponds to the mother nuclide.

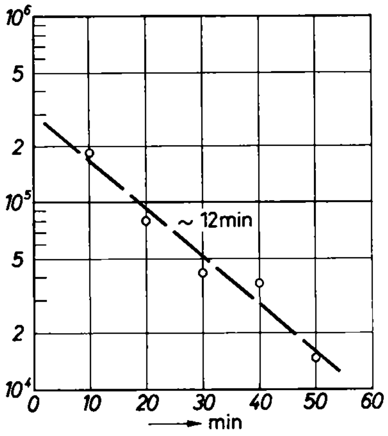

Fig. 7. ^{88}Zr activities milked from niobium at 10 min. intervals. The activities correspond to the integrated gamma peak at 395 keV measured after 40 days

The unknown ^{87}Nb, which is likely to have a short half-life, is also expected to be produced at 50 MeV deuteron irradiations on zirconium. With the usual extraction procedure a pure niobium sample was obtained 15 min after the end of irradiation, let to decay for about 10 min, after which the grown-in zirconium fraction was isolated. Little beta activity was found in this sample. Gamma measurements showed the 4.4 min 590 keV line of ^{89m}Zr and a small amount of the 920 keV line of ^{89}Zr (^{89m}Y). No activity due to ^{87}Zr could be established. It may be concluded that the amount of ^{87}Nb produced by a 50 MeV deuteron bombardment on zirconium is too small to be detected this way, or that the half-life of ^{87}Nb is shorter than about 4 min. A short irradiation of zirconium at a deuteron energy of 50 MeV and an immediate measurement of the gamma spectrum without previous chemical separation, also failed to show new lines.

4. Results for ^{88}Nb and discussion

The 13.6 min half-life must be assigned to ^{88}Nb for the following reasons:

1. It is only produced in deuteron bombardments on natural zirconium if the energy is higher than 30 MeV, which is about the threshold for the (d, 4n) reaction.
2. It is produced by 100 MeV alpha bombardments on yttrium.
3. Interval milkings of ^{88}Zr show its parent nuclide to have a half-life between 11 and 18 min.

The result of a quantitative analysis of the scintillation gamma spectrum of ^{88}Nb applying the substraction method [16], is shown in Table 1.

Table 1. *Relative intensities of gamma rays belonging to the decay of ^{88}Nb. The value for the annihilation peak is arbitrary. Electron conversion has not been taken into account*

MeV	%	MeV	%
1.080	35 ± 5	0.40	15 ± 5
1.058	35 ± 5	0.27	13 ± 5
0.67	25 ± 5	0.075	5 ± 3
0.51	100		

By means of a collimator, which reduced the intensity of the 511 keV line both in ^{88}Nb and in a ^{22}Na standard, it could be proved that the 511 keV peak is caused by annihilation.

An estimate of the amount of β^+/γ radiation in ^{88}Nb could be obtained comparing the intensities of the annihilation peak and the strongest gamma peak. ^{22}Na, measured in the same conditions, was used as a standard. It was found that there is one β^+ per 1.080 (or 1.058) MeV gamma ray, within an accuracy of $\pm 10\%$.

The values reported here for the half-life of ^{88}Nb and for the energies of the accompanying gamma rays, agree well with the values reported by KORTELING [1]. They differ from those published by BUTEMENT and QUAIM [2].

With the data now at hand, it is not possible to order the levels in ^{88}Zr but inferences may be drawn from neighbouring nuclides. A possible decay scheme for ^{88}Nb is presented in Fig. 8, where the levels are compared to those of ^{90}Zr and ^{86}Sr.

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The total energy available for the decay of ^{88}Nb is near 8 MeV [17], [18]. If the sum gamma energy in the decay is substracted from this value, a maximum β^+ energy near 4 MeV remains. Together with the 13.6 min half-life, this results in a log ft value of 5.9, indicating an allowed or first forbidden transition. To establish the spin of the excited state in ^{88}Zr populated by the decay of ^{88}Nb, it would help to know the spin of the ground state of ^{88}Nb. For ^{90}Nb [with the proton(g 9/2)^1 and neutron (g 9/2)$^{-1}$ configuration] this is known to be 8 + or 9 +, where the first value is to be preferred [19] in agreement with the BRENNAN-BERNSTEIN rules [20]. For ^{88}Nb [with the proton (g 9/2)^1 and neutron (g 9/2)$^{-3}$ configuration] the same value is to be expected for the ground state. The 9/2 + ground states of $^{85}_{38}$Sr$_{47}$ and $^{83}_{36}$Kr$_{47}$ agree with the g 9/2 value for the neutron (g 9/2)$^{-3}$ configuration. If then 13.6 min ^{88}Nb has spin 8 or 9, the level fed directly in ^{88}Zr should have a spin not lower than 7. The situation is similar in ^{90}Zr, where the 8 + level at 3600 keV is fed by the β^+ decay of ^{90}Nb.

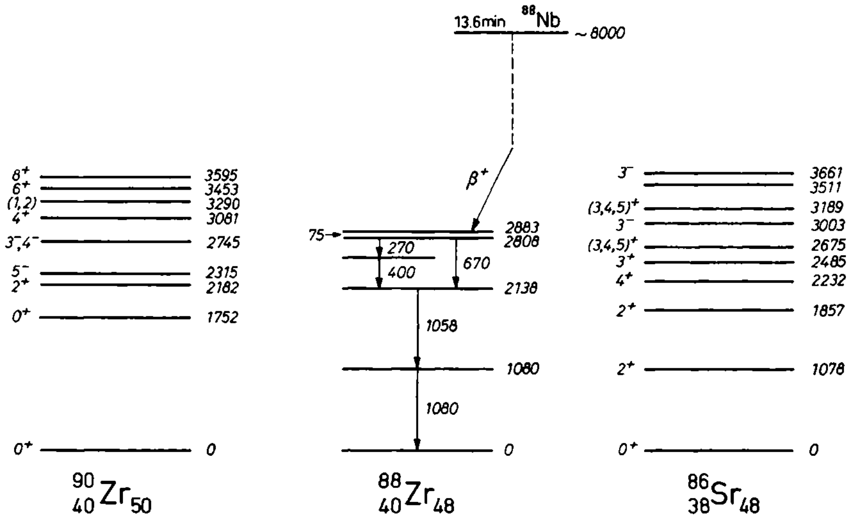

Fig. 8. Possible decay scheme of ^{88}Nb with a comparison of known levels in ^{90}Zr (mainly from ref. [3]) and in ^{86}Sr (from ref. [7]). Spin assignments are discussed in the text. The relative positions of the 270 and 400 keV gamma transitions in ^{88}Zr may be inverted

As to the first excited level of ^{88}Zr, comparisons may again be made with the nuclides with similar structures. The first levels in ^{90}Zr are interpreted as 2 proton levels and all are higher than 1700 keV. The first levels in ^{86}Sr have been interpreted as vibrational levels [7], or by a shell model, where they represent excitations of the (g 9/2)$^{-2}$ neutron configuration [8]. The first excited state is the 2 + level at 1078 keV. Since the spectrum of ^{88}Nb has a gamma line at nearly exactly this energy, we take this to be the first excited 2 + state in ^{88}Zr. The next level could be 0 +, 2 + or 4 +. The spin would have to be high however, if a spin of 8 is to be reached at the highest level found in ^{88}Zr. In ^{86}Sr the 4 + state is at 2232 keV and in ^{90}Zr at 3081 keV above the ground level. The gamma line at 1058 keV may then be the 4 + to 2 + transition in ^{88}Zr, which places the 4 + state at 2138 keV. The levels at 2808 and 2883 keV could then have the 6 + and 8 + values respectively. The level between 2808 and 2138 keV may be the 5− level, which in ^{90}Zr is placed at 2320 keV. The relative position of the 270 and 400 keV transitions in the decay of ^{88}Nb is not known and they may be in the inverted order from the one indicated in Fig. 8.

The 75 keV transition may be useful in clearing up the decay scheme of ^{88}Zr in future experiments. This transition should have a measurable half-life and coincidence measurements could place this transition in the decay scheme. In our case the resolving time of the conversion electron – gamma ray coincidence circuit used did not permit a conclusive placing. For an E2 transition, a half-life between 10^{-5} and 10^{-6} s is the WEISSKOPF estimate [21]. For an M2 transition this value should be nearer to 10^{-4} s. Our measured K/L + M conversion ratio agrees best with an E2 transition. The theoretical values [22] are 3.25 for an E2 and 4.30 for an M2 transition.

If the level structure of ^{88}Zr as represented in Fig. 8 is correct, with the spin and parity assignments mentioned above, a marked similarity exists between this structure and that of $^{92}_{42}$Mo$_{50}$ as found through the decay of ^{92}Tc [23]. In ^{92}Mo the 8 + level is also populated through the β^+ decay of 4 min ^{92}Tc, which also

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has spin 8 or 9 and parity +. The experimentally found levels in ^{92}Mo with positive parity, are interpreted as belonging to the proton $(g\,9/2)^2$ $(p\,1/2)^2$ configuration [9]. These may well be comparable to the levels in $^{88}_{40}Zr_{48}$ where the lowest configuration would be neutrons $(g\,9/2)^{-2}$; protons $(p\,1/2)^2$.

Some levels in ^{88}Zr have recently become known through the ^{88}Sr (alpha, 4n) ^{88}Zr reaction, by measuring the accompanying gamma rays [24]. Values of 510 ± 7; 800 ± 15; 940 ± 15 and 1080 ± 30 keV were found. Of these, only the 1080 keV gamma line agrees with the transitions found through decay of ^{88}Nb.

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14.8 MeV Neutron Activation Cross Sections for ^{181}Ta(n, α) $^{178m,\,g}$Lu and ^{178}Hf(n, p) $^{178m,\,g}$Lu*

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Summary Absolute neutron activation cross sections have been measured for the production of 16 and 30 minutes ^{178}Lu from ^{181}Ta and ^{178}Hf at a neutron energy of 14.8 MeV. The observed reactions and the corresponding cross sections are: ^{178}Hf (n, p) ^{178}Lu (16 minutes), 1.02 ± 0.10 mb; ^{178}Hf (n, p) ^{178}Lu (30 minutes), 1.72 ± 0.17 mb; ^{181}Ta (n, α) ^{178}Lu (16 minutes), 0.14 ± 0.04 mb and ^{181}Ta (n, α) ^{178}Lu (30 minutes), 0.30 ± 0.10 mb.
The existence of the 16 and 30 minutes half lives for ^{178}Lu has been confirmed.

Zusammenfassung Es wurden absolute Neutronenaktivierungsquerschnitte für die Erzeugung von ^{178}Lu mit 16 und 30 min Halbwertszeit aus ^{181}Ta und ^{178}Hf bei einer Neutronenenergie von 14,8 MeV gemessen. Die beobachteten Reaktionen und die entsprechenden Querschnitte sind: ^{178}Hf(n, p) ^{178}Lu (16 min) 1,02 ± 0,10 mb; ^{178}Hf(n, p) ^{178}Lu (30 min) 1,72 ± 0,17 mb; ^{181}Ta (n, α) ^{178}Lu (16 min) 0,14 ± 0,04 mb; und ^{181}Ta (n, α) ^{178}Lu (30 min) 0,30 ± 0,10 mb. Die Existenz von ^{178}Lu mit Halbwertszeiten von 16 und 30 Minuten wurde bestätigt.

Résumé On a mesuré la section absolue de la réaction produisant du ^{178}Lu de période 16 et 30 minutes par irradiation du ^{181}Ta et du ^{178}Hf à l'aide de neutrons de 14,8 MeV. Les réactions observées et les sections correspondantes sont ^{178}Hf (n, p) ^{178}Lu (16 minutes) 1,02 ± 0,10 mb; ^{178}Hf(n, p) ^{178}Lu (30 minutes) 1,72 ± 0,17 mb; ^{181}Ta (n, α) ^{178}Lu (16 minutes) 0,14 ± 0,04 mb et ^{181}Ta (n, α) ^{178}Lu (30 minutes) 0,30 ± 0,10 mb. L'existence des périodes 16 et 30 minutes pour ^{178}Lu a été confirmée.

I. Introduction

There have been several conflicting reports concerning the half life and decay of ^{178}Lu. POULARIKAS et al. [1] found a 22.0 ± 0.5 minute activity of ^{178}Lu which they produced by the ^{181}Ta (n, α) reaction using 14.8 MeV neutrons. Later, KUROYANAGI et al. [2] reported the existence of two states of ^{178}Lu, one decaying with a half life of 16 minute and the other decaying by a half life of 30 ± 5 minutes. ATEN et al. [3] found 4.5 minute and 22 minute activity of ^{178}Lu while bombarding hafnium with 30 MeV neutrons. Recently, BAKHRU and MUKHERJEE [4] reported 5 minute and 30 minute half lives for ^{178}Lu. They assigned the 5 minute activity to the ground state of ^{178}Lu and the 30 minute activity to a meta-stable state of ^{178}Lu. MUKHERJEE and BAKHRU [5] reported the (n, α) cross-section values for the production of 30 and 5 minute ^{178}Lu from ^{181}Ta using 14 MeV neutrons [^{181}Ta(n, α)^{178}Lu (30 minutes), 1.2 ± 0.2 mb; ^{181}Ta(n, α)^{178}Lu (5 minutes), 0.5 ± 0.3 mb]. The present investigation was undertaken from the viewpoint of measuring the production cross sections of the two states of ^{178}Lu from ^{181}Ta and ^{178}Hf as well as a precise determination of their respective half lives.

II. Target Material

The ^{178}Lu activities were produced by irradiating gram quantities of reagent grade tantalum pentachloride and the oxide of enriched ^{178}Hf weighing 21.5 mg. The

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