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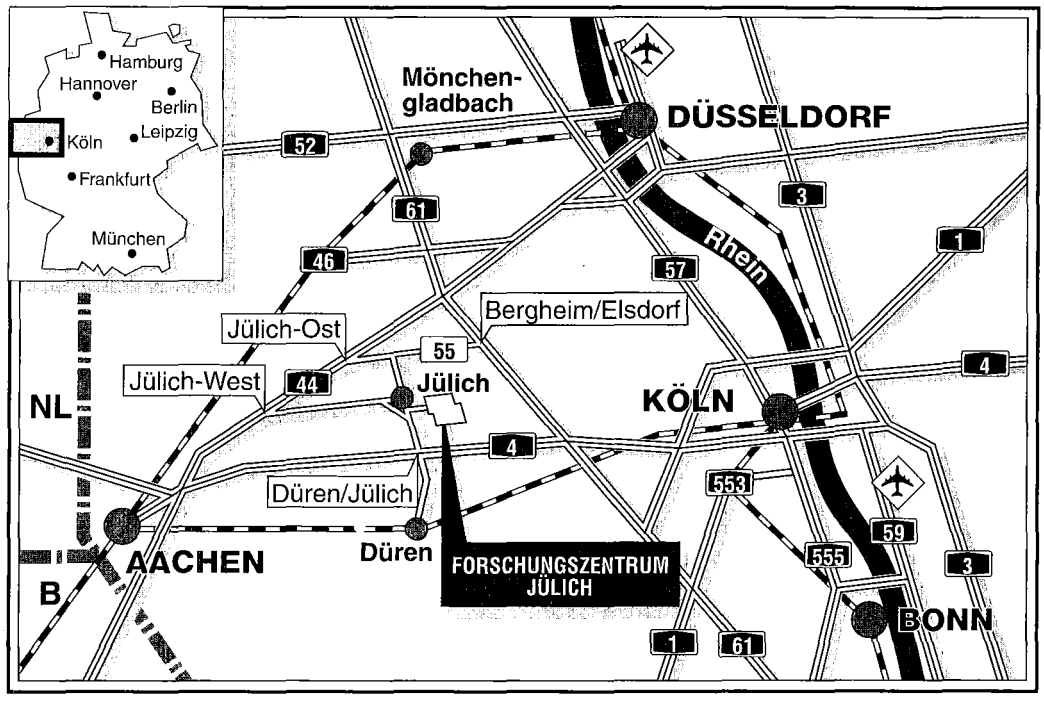

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Abstract

In a tantalum target used in the Spallation Neutron Source ISIS of the Rutherford Appleton Laboratory the spallation products are to be determined in order to obtain a reliable data basis for the calculation of spallation yields by appropriate computer programs. These calculations are required for the construction of targets for other spallation neutron sources, especially the European Spallation Source (ESS), for the planning of which a project has been started at the Research Center Jülich. Nuclide specific detection methods such as mass spectrometry and nuclear counting techniques are suitable for the determination of the spallation products. This report attempts to identify which techniques of chemical analysis available at the Research Center Jülich can be used, which spallation products can be determined by them and for which methods developments, improvements and adaptations will be necessary.

An important role is played by chemical separation techniques, because most of the counting and measurement techniques cannot be applied directly to solid samples taken from the target. For most spallation products well-tried separation procedures are not yet available and have to be developed with special respect to the conditions of the highly radioactive tantalum matrix. The stable nuclides in the spallation products, which represent the majority, can probably be measured by the "ELEMENT" mass spectrometer in operation at the Central Department of Analytical Chemistry (ZCH), which has a good mass resolution and very low limits of determination. Developmental work is in progress with this instrument for on-line separation procedures by HPLC for some of the most interesting spallation products. Gamma-ray spectrometers are readily available including procedures for the evaluation of the spectra, but some developmental work is necessary to include the many neutron deficient radionuclides in the nuclide catalogue required for the automatic identification of the radionuclides by the computer program used for interpretation of the spectra. The next rank in the measurement methods is occupied by liquid scintillation counting. It is suitable for those nuclides emitting only β-rays or low-energy X-rays and atomic electrons. In every case, the radionuclides must be separated and highly purified before this counting technique can be applied. Low-energy photon spectrometry might also be useful but is not readily available at the ZCH. Alpha-spectrometry is required for only a few nuclides and might possibly be carried out with samples from a separated fraction containing only the heavy rare earth elements. Neutron activation analysis will be used in the analysis of "background material", i.e. of parts from the edges of the target distant from the primary proton beam and practically not exposed to the spallation process, if such parts can be found. Neutron activated samples of tantalum will also be used in the development of separation procedures for the chemical elements to which spallation products belong, because many of the impurities present in tantalum yield neutron activation products and most of them can also be found as radioactive spallation products in the target.

Preface

A previous version of this report was published in April 1995 as an internal Technical Note (TN ZCH-RCA 95APR01). Meanwhile, at the KFA a research program "Developmental Work for an European Spallation Source" has been started. A wider audience is now interested in this report and an English edition is desirable. The development of analytical procedures for the determination of spallation products has begun in the Central Department of Analytical Chemistry and some of the results can be considered in this revised edition. Delivery of the target to the Research Center Jülich, where it will be cut up in the Hot Cell Laboratories, has been delayed by several months, so that a number of short-lived spallation products might have decayed and cannot longer be measured. Now it is assumed that analytical samples will be available after the first quarter of 1997 and 1 April 1997 has been chosen as the new reference date for the calculation of amounts and activities of the spallation products.

Thanks are due to J. S. Becker, F. Carsughi and G. Küppers who provided some of the information given in this report, and Mrs. Carter-Sigglow for having corrected the English text.

Table of Contents

1.0 Introduction

At the Research Center Jülich (KFA), a tantalum target from the spallation neutron source (ISIS) of the Rutherford Appleton Laboratory (RAL) will be dismantled and cut up for material investigations. This work is part of a project for planning a European Spallation Source (ESS). One of the intended investigations is the determination of the contents and the local distribution of the spallation products, and the Central Department of Analytical Chemistry (ZCH) has been asked to perform these analyses.

For this reason, we had to consider which analytical techniques available at the ZCH might be suitable for this task. The decisive criterion was obviously the determination limits attainable by an analytical technique, because with many spallation products the contents were expected to be below 10^{-9}g/g. Calculations performed at RAL were available for estimating these contents.[1] The aim of the determination of spallation products was to check the accuracy of the computer programs and the data bases used for these calculations and from the experimental results to gain a new data basis for new calculations to be done at RAL and KFA. An accurate knowledge of the spallation yields is required mainly for the estimation of the radiation dose rate and the nuclear heat generated in the target when, after use, it has to be stored as nuclear waste.

In this report an overview is given of analytical techniques which may be suitable for the determination of the spallation products in the target. For the radioactive nuclides amongst the spallation products nuclear radiation measurements and techniques of radiochemical analysis have to be applied, whereas stable nuclides can be only determined with mass spectrometry. The analytical procedures must be able to determine the spallation products in the concentrations present in the target. A rough estimate of the contents expected in the ISIS target to be investigated can now be gained from the calculations done at RAL.

2.0 Data provided by the RAL calculations

The target to be dismantled has a weight of 30 kg and is made of tantalum plates of different thicknesses. It was irradiated with a proton beam of 800 MeV at a current of 150 μA for 500 days, which corresponds to 1.74 Ah or an amount of ≃ 4×10^{22} protons. Yields, i.e. the weights of spallation products accumulated over the irradition time, have been calculated by a computer program at the RAL for about 330 spallation products. For radioactive nuclides, the activities were also calculated. One set of data refers to the end of irradiation, which was 29 June 1994, and another set refers to 1 February 1995, i.e. the weights and the activities are recalculated for radioactive decay for that date. The results were communicated as a computer printout.[1] The data set for 1 February 1995 was used for the recalculations done in this report, and these data are listed in Columns 3 (amounts) and 4 (activities) of Table 2 in the Appendix.

3.0 Recalculations for the conditions of chemical analysis

Only small pieces of the target will be used for radiochemical analysis and it is assumed that samples of about one gram are provided for this purpose and sub-samples have to be taken for the different methods of analysis. We have to calculate the activities of such pieces in order to estimate, whether they can be handled in the chemical laboratory and to assess which analytical technique can determine the spallation products. Because the target will presumably be cut up in the first months of 1997 and samples for chemical analysis will be available thereafter, amounts and activities were recalculated for the decay of the radioactive nuclides and the build-up of their stable and long-lived daughter nuclides for 1 April 1997.

The recalculations in this report started from the amounts (weights) of the spallation products on 1 February 1995 as calculated by RAL (Column 3 of Table 2 in the Appendix, data marked by an asterisk). For radionuclides the activities, A_t, were calculated from the weights, m_t, by

$$A_t = \frac{N_A\, m_t}{M}\ \frac{\ln 2}{t_{1/2}} \qquad [1]$$

The subscript t means target; N_A is Avogadro's number, 6.022×10^{23}, M is the atomic weight and $t_{1/2}$ is the half-life (s). Note that the values of Columns 3 and 4 in Table 2 refer to the whole target and are given in gram (amounts) or TBq (activities). For some short-lived radionuclides only activities were given in the RAL printout and these are marked by an asterisk in Column 4 of Table 2. The weights of these nuclides were calculated by Equation 1 after rearrangement for m_t.

Contents of spallation products and activities, as may be expected in analytical samples, are calculated for 1 g of target material and the sampling date was assumed to be 1 April 1997. These values were calculated as contents or mean specific activities, i.e. as grams of spallation product per gram or as becquerels per gram of target material. The amounts, m_s, were calculated by

$$m_s = \frac{m_t}{30000}\, e^{-\frac{\ln 2\, t_w}{t_{1/2}}} \qquad [2]$$

In some cases radioactive daughter products have to be considered and their amounts, $m_{s,d}$, are

$$m_{s,d} = \frac{t_{1/2,d}}{t_{1/2,p} - t_{1/2,d}}\ \frac{m_{t,p}}{30000} \times \left(e^{-\frac{\ln 2\, t_w}{t_{1/2,p}}} - e^{-\frac{\ln 2\, t_w}{t_{1/2,d}}}\right) + \frac{m_{t,d}}{30000}\, e^{-\frac{\ln 2\, t_w}{t_{1/2,d}}} \qquad [3]$$

m_t is the amount in the target on 1/2/95, and m_s that in a sample of 1 g on 1/4/97; $t_{1/2}$ are the half-lives. The subscripts p and d refer to the parent and the daughter nuclide, respectively. t_w is the waiting time, 789 days. From the new weights the activities were found by Equation 1. The increase in weights of stable or long-lived nuclides caused by the decay of their predecessors was also calculated.

The values calculated by RAL also include some very short-lived radionuclides with half-lives shorter than a few days. They are daughters of long-lived radionuclides and are considered to be in transient equilibrium with them, i.e. they have practically the same activities as their predecessors.

4.0 Basic problems

4.1 Determination limits

Although with some analytical techniques the limits of determination may be estimated quite well, not all factors influencing them are readily predictable. With the ICP-MS "ELEMENT" determination limits below 10^{-12}g can be attained for most elements, but the determination limit with respect to the content in the sample itself depends on the amount of solution, i.e. on the aliquot of the original sample, which can be introduced into the instrument. And this amount depends on the activity of the radionuclides in the solution. With γ-ray spectrometry the determination limits depend on the energies and the intensities of the γ-lines and may be affected by interfering lines from other nuclides. Other factors may influence the limits of determination with other counting techniques. These aspects and some others of significance in the investigation of the irradiated tantalum target, have to be kept in mind when suggestions concerning the suitability of an analytical technique are made. However, the remarks in this report should be regarded as a first step in the planning of the work to be done at ZCH in cooperation with the other institutes engaged in the treatment of the ISIS target.

4.2 Impurities in the tantalum target

The purity of tantalum available in the amounts required for the production of a target is not better than 99.9%. Many of the impurities making up the residual 0.1% are chemical elements, the nuclides of which will also appear as spallation products, except the radionuclides. This means that in measuring stable nuclides by mass spectrometry a bias concerning nuclides present always has to be considered. As long as the amount of a spallation product is higher than the amount of the same nuclide present as an impurity, the measured values may be corrected for this background. Additional information for the evaluation of the mass spectra may be obtained from the natural isotopic ratios of the elements, from which the isotopic ratios in the spallation products will essentially deviate.

The corrections for the background caused by the impurities can only be performed if their contents in the target material are accurately known. However, no information on the material used is available nor are there any remains of that material which might be used for an analytical investigation to obtain "background values" for the impurities. Assuming that there are only a few producers of tantalum two different tantalum materials, as presently available, have been analyzed by mass spectrometry [2] and by neutron activation analysis [3]. The contents of trace impuritites in the two specimens were very different in the case of some elements, so that they cannot serve as "typical" tantalum specimens, i.e. as reference material.

Therefore attempts should be made to obtain "non-irradiated" target material from the target itself. There are good reasons to assume that some areas near the edges of the irradiated target contain practically no spallation products and are also not essentially influenced by other nuclear reactions. From these parts samples have to be taken and analyzed for impurities by sensitive methods of multielement trace analysis such as ICP-MS and NAA, and, if the samples are not too radioactive, also methods of solid-state mass spectrometry should be applied to obtain background values for the impuri-

ties interfering with the determination of the spallation products.

The limits of determination and the accuracies attainable by the analytical procedures will strongly depend on the contents of impurities found in the target material, on the precision and accuracy with which they can be determined and on the homogeneity of their occurrence in the target.

4.3 Inhomogeneous distribution of spallation products

The target was exposed to a primary proton beam of about 8 cm diameter around its central axis. Scattered protons hit other parts of the target and may undergo spallation or other nuclear reactions according to their energies. From this fact it is obvious that the spallation products are not at all equally distributed over the target, but no data are available for the distribution functions along the axis and the radii of the target. In this respect one or another of the analytical techniques proposed may fail to satisfy the limits of determination with samples from weakly exposed parts of the target.

4.4 Isobaric nuclides

Among the spallation products there are many pairs and triplets of isobaric nuclides. Although the ICP-MS "ELEMENT", which will be used in the analysis of the target, has a good mass resolution, it is not able to differentiate between two nuclides with the same mass number, e.g. ^{93}Zr and ^{93}Nb. Such pairs have to be chemically separated before they can be quantified by ICP-MS. In some groups of isobaric nuclides the amount of one nuclide is much higher than that of the others and the sum of contents of the isobars measured by ICP-MS can also be considered as the content of the predominant nuclide because the contributions of the other nuclides can be neglected. An example is the pair with mass number 164 where the amount of the isotope of Dy is only ≈ 1/1000 of the amount of the isotope of Er. In many cases, out of a group of isobars one or more are radioactive nuclides which have decayed to small amounts and they will not interfere with the determination of their stable isobars and can be measured by a nuclear counting technique.

All of the stable spallation products and also some of the long-lived radionuclides can be determined by ICP-MS, if the individual elements in the sample are chemically separated. ICP-MS with on-line HPLC promises to become a useful technique for this purpose, by means of which special procedures can be "tailored" to groups of elements especially important for understanding the spallation process.

4.5 Sum contents of isobaric nuclide groups

Since all chemical separation procedures require, in general, a greater expense of manpower than instrumental measurements, it is obvious that not all spallation products in all samples to be taken from the target can be determined in this way. A comparatively simple and effective separation procedure is the removal of tantalum and, possibly, of some radionuclides with high activities. In the residual solution the sums of the weights or contents in all groups of isobars can be measured by ICP-MS. These values will allow a good general check on the validity of calculated spallation yields. Therefore, these sums have been calculated (see Table 3 in the

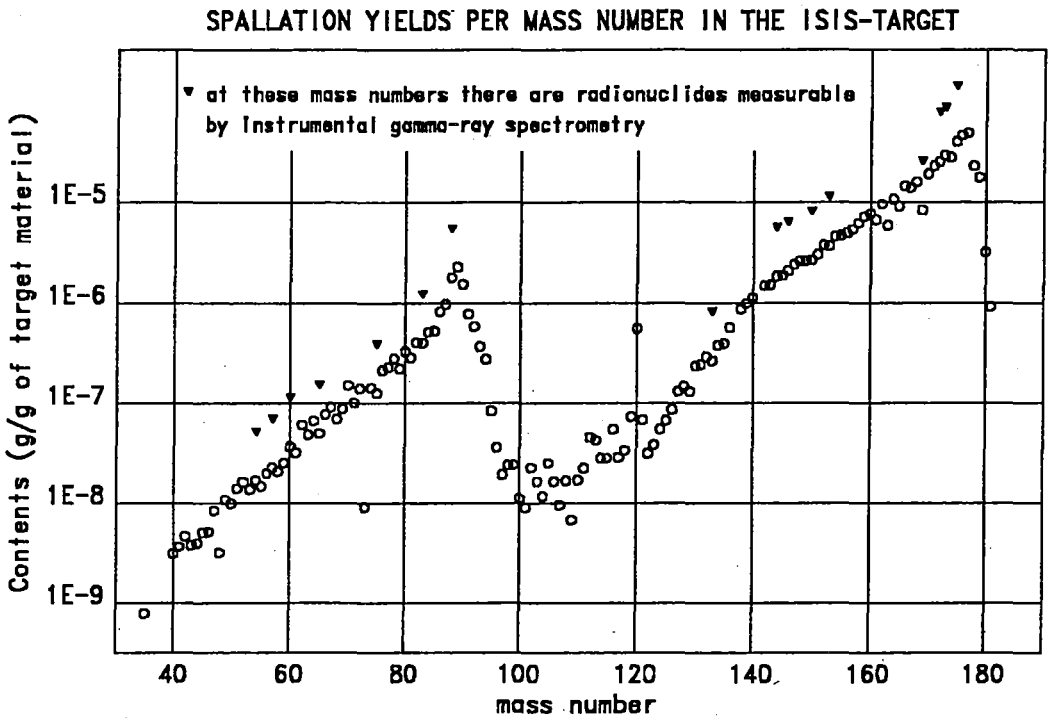

Figure 1 Mass spallation yields: Sums of the contents of nuclides with the same mass numbers in the ISIS target (following calculations at the Rutherford Appleton Laboratory [1]).

Appendix) and are shown in a graph in Figure 1.

4.6 Noble gases

Twenty of the spallation nuclides are isotopes of noble gases. None of these can be measured in the solid sample by γ-ray spectrometry. For all other measurement techniques the sample has to be dissolved and in doing so the noble gases will escape from the solution and are lost for further analysis. But this process can also be understood as a separation procedure for these elements and, if the sample is dissolved in a closed apparatus, the noble gases can be collected in an ampoule and further investigated by γ-ray spectrometry, low-energy photon spectrometry and/or by ICP-MS. A device for handling small volumes of radioactive gas is, however, not available at ZCH.

5.0 Analytical techniques

In the following the analytical techniques are described which seem suitable for the nuclide analysis of the target. The nuclides which may be preferably determined by each of the techniques are listed in Table 1. The problems and restrictions discussed in the previous Chapter should always be kept in mind when considering the suitability of the analytical techniques.

5.1 Radiochemical separations

Only a very few spallation products can be measured by non-destructive analytical methods, i.e. only some γ-ray-emitting nuclides can be determined by purely instrumental γ-ray spectrometry (see Row 4 in Table 1 in the Appendix). Their activities and also those of other radionuclides present with high activities but emitting only X-rays or β-radiation will interfere with the γ-measurement of most other nuclides present with lower activities. The interfering nuclides have to be removed from the samples by radiochemical separations. Such separations are also necessary before any other measurement technique can be applied: mass spectrometry, β- or X-ray counting.

Four strategies with chemical separations have to be considered:

Separation of the matrix tantalum

It is assumed that in the target a small share of neutrons is moderated so that ^{182}Ta is built up by (n,γ)-reactions, and, during the long irradiation time a high activity of this nuclide is accumulated. However, no information about this "thermal" neutron flux could be obtained. The removal of the main activity is necessary when mass spectrometry has to be applied, because the instruments must not be unnecessarily contaminated by radioactivity. It is also desirable to prevent contamination from inactive tantalum.

The separation of the matrix might also be useful when nuclear counting techniques are to be used in order to reduce the level of interfering radiations and to avoid self-absorption of low energy γ-rays in the sample.

A separation procedure for tantalum which enables good separation factors from nearly all other elements has been developed by KÜPPERS [3].

Group separation of main interfering activities

Even if the assumption of a noteworthy thermal neutron flux in the target doesn't prove to be true and ^{182}Ta is not the predominant activity, radioactive spallation products of tungsten, tantalum, hafnium and lutetium may cause a high dose rate of the sample and these elements have to be removed as a group before measurements with the mass spectrometer can be started or radionuclides with lower activities can be measured by γ-ray spectrometry. Radionuclides which can probably be measured after the separation of tantalum or of the group of strongly radioactive nuclides are listed in Row 5 of Table 1.

Separations of single elements

These will be necessary for the determination of

- individual nuclides by mass spectrometry,
- radionuclides emitting only β-rays,

- radionuclides by low-energy photon spectrometry,
- radionuclides with very low activities by γ-ray spectrometry,
- radionuclides emitting α-rays by α-spectrometry.

In the last case, a separation of the group of rare earth elements may be sufficient, because only three nuclides have activities high enough to be measured and they all belong to this group.

On-line separations

High-performance liquid chromatography (HPLC) can be applied to the separation of chemical elements and the instrument may be coupled to a mass spectrometer so that the separated fractions are immediately fed into the plasma ion source of an ICP-MS. Such procedures are under development at ZCH.

5.2 Mass spectrometry

Most spallation products are stable nuclides and they have to be determined by mass spectrometry. For solid-state mass spectrometry the samples will be too radioactive and cannot be directly inserted in the instrument. More promising is the application of mass spectrometry with an inductively coupled plasma ion source (ICP-MS) [4]. This technique requires dissolution of the target material in an acid mixture. Additionally, the matrix tantalum - the stable as well as the strongly radioactive unstable nuclides of this element - has to be chemically separated in order to avoid contamination of the instrument. Separation procedures in which tantalum is removed by liquid-liquid extraction have been developed [2,3]. This technique will allow the determination of the sums of contents for nearly all groups of isobars (see Sections 4.4 and 4.5), except those containing noble gases (see Section 4.6). From the tantalum-free solution small aliquots, which have low activities and radiation dose rates, can be taken and analyzed with ICP-MS. The mass numbers of the groups of isobars for which the sums of the weights can be determined by this technique and the single nuclides whose amounts can be similarly determined are listed in the first row of Table 1.

More effective but also more expensive is the separation of the spallation products into small groups of elements or the isolation of the elements themselves. Then nearly all stable nuclides in the spallation products can be determined. As mentioned above, online HPLC seems to be a promising technique for this purpose.

5.3 Gamma-ray spectrometry

Radionuclides emitting γ-rays can be easily measured with a γ-ray spectrometer and programs calculating the absolute activities from the peak counting rates and for corrections of the radioactive decay are available in the Division of Radiochemical Analysis (RCA) of the ZCH. However, in our laboratory mainly neutron activation and fission products, i.e. preferably neutron-rich radionuclides, have been dealt with up to now. Amongst the spallation products there are many nuclides "from the other side of the valley of stability", which have a neutron deficiency. Therefore, the treatment of the γ-ray spectra from spallation samples will require a new γ-ray catalogue containing all the nuclides expected to be found among the spallation products of tantalum and only those. These data may be taken from the GAMDAT catalogue [5], a data file which is also stored on the computer of the γ-ray

spectrometer. With some nuclides the decay data in this file may have to be replaced by those of more recent compilations [6]. In the nuclides predicted to be measurable in Table 1 line interferences have not been considered and may inhibit the measurement of one nuclide or another.

The γ-ray- emitting nuclides with the highest activities can be measured in the samples without any chemical pretreatment. The surface may have to be etched to remove contaminations caused by sample handling in the hot cells. When samples of ≃ 1 g have to measured, corrections for γ-ray self-absorption are necessary.

Gamma-ray emitting nuclides with activities predicted three to six orders of magnitude lower than those of the most active nuclides might be measured after removal of these active nuclides, mainly those of tantalum, tungsten, hafnium and lutetium. Nuclides probably to be found in this group are listed in Row 6 of Table 1.

There remain some γ-ray-emitting nuclides with activities $<10^2$ Bq/g. In these cases the elements of the nuclides concerned have to be chemically isolated to avoid interference from the Compton background and bremsstrahlung of the more active nuclides.

When the activities are below 1 Bq/g the low-level γ-ray spectrometer of the ZCH should be used for the measurements, but activities below 10^{-2} or 10^{-3} Bq/g probably cannot be measured in our laboratory.

5.4 Liquid scintillation counting (LSC)

LSC is a powerful technique for counting nuclides which emit particles. For these it has a counting efficiency of nearly 100%. LSC is mainly used for β-counting, but α-rays, atomic electrons and X-rays emitted during radioactive decay processes can also be measured. The technique is, however, not able to determine more than two nuclides simultaneously in practical application, because the energy resolution is very poor and β-spectra have a broad distribution without distinct lines. Therefore, radionuclides can be measured only if they are well purified by radiochemical separations. Radioisotopes of the same elements cannot be separated by these techniques and only under certain circumstances - e.g. if one nuclide has a strongly predominant activity or if the maximum β-energies are quite different - will LSC lead to useful results. LSC is routinely carried out at ZCH but appropriate separation procedures have to be developed for nearly all spallation products mentioned in Row 11 of Table 1.

5.5 Low-energy photon spectrometry (LEP)

Gamma-ray spectrometers usually have a low detection efficiency for γ-rays and X-rays below, say, 60 keV but special detectors are available for this purpose. In Row 10 of Table 1 nuclides are listed which might be measured by this technique. However, this technique, which does not only require special detectors but also special procedures and experience in spectra evaluation and interpretation, is not available at ZCH. Many of the nuclides accessible by LEP might also be measurable by LSC. An advantage of LEP is the better energy resolution, so that interferences by nuclides not completely chemically separated may be recognized and, occasionally, corrected for. A disadvantage is its lower counting efficiency and the strong self-absorption of the low-energy photons, which moreover strongly depends on the photon energy, in the counting samples.

5.6 Alpha-ray spectrometry

A few nuclides, mainly isotopes of some heavy rare earth elements, emit α-radiation. There is no experience, however, of how reliable the decay data of these nuclides are. Three nuclides, ^{148}Gd, ^{150}Gd, and ^{154}Dy have activities high enough to be measured with an α-ray spectrometer after chemical separation of the elements. Alpha-ray spectrometry is routinely performed at ZCH.

5.7 Neutron activation analysis

Another technique for the determination of stable and very long-lived nuclides might be neutron activation analysis. It must be applied after chemical separation of the matrix tantalum, because, when irradiated with neutrons in a reactor, the matrix tantalum itself produces a long-lived radionuclide, ^{182}Ta, $t_{1/2}$ 115 d, with a very high activity, which will interfere with all other activation products. After removal of tantalum, however, many different activation products might be found and those of isobar pairs may differ in their nuclear properties, e.g. in their γ-spectra. The technique has been applied to tantalum irradiated with neutrons in a nuclear reactor and a great number of elements present as impurities were determined [3].

6.0 Presentation of results

The results of the calculations and the considerations about suitable analytical techniques are presented in tabular form in the Appendix. Table 1 provides an overview of the analytical procedures and the nuclides for which they may be applicable. Table 2 gives the list of all spallation products considered in the RAL calculations, their amounts and activities in the target, the mean contents and activities in a sample of 1 g on 1 April 1997, and suitable analytical techniques for their determination. In Table 3 the groups of isobaric nuclides are listed and the sums of their contents are calculated.

7.0 References

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8. G. Küppers, private communication.

Appendix A. Table 1 - Analytical procedures and the nuclides for which they are useful

Analytical technique	Nuclides measurable
Mass spectrometry after chemical separation of tantalum and possibly other radionuclides with very high activities, e.g. those mentioned in "Gamma-ray spectrometry without chemical pretreatment".	Sums of contents of nuclides with the same atomic weights, and contents of nuclides of which only one per mass number is present or is predicted to be in excess by at least two orders of magnitude. Noble gases are assumed to be expelled when the tantalum sample is dissolved. Their nuclides cannot be measured and they do not interfere with the determination of isobaric nuclides. Some of the nuclides mentioned in the following lists may have been separated according to the separation procedure chosen and they cannot, of course, then be determined. Mass numbers for which the sums of the contents of the isobaric nuclides can be measured: 41, 46, 50, 53, 54, 55, 58, 59, 60, 63, 64, 70, 74, 76, 79, 87, 91, 92, 93, 94, 96, 97, 98, 99, 100, 101, 102, 104, 106, 107, 108, 110, 112, 113, 115, 116, 120, 121, 122, 123, 133, 136, 137, 138, 142, 144, 146, 148, 150, 152, 154, 156, 157, 160, 161, 162, 163, 166, 168, 170, 172, 173, 174, 176, 179 Single nuclides, which are probably not interfered with by isobaric nuclides: ^{43}Ca, ^{44}Ca, ^{45}Sc, ^{47}Ti, ^{48}Ti, ^{49}Ti, ^{51}V, ^{52}Cr, ^{52}Cr, ^{56}Fe, ^{57}Fe, ^{61}Ni, ^{62}Ni, ^{65}Cu, ^{66}Zn, ^{67}Zn, ^{68}Zn, ^{69}Ga, ^{71}Ge, ^{72}Ge, ^{73}Ge, ^{75}As, ^{77}Se, ^{78}Se, ^{80}Se, ^{81}Br, ^{84}Sr, ^{85}Rb, ^{86}Sr, ^{88}Sr, ^{89}Y, ^{90}Zr, ^{95}Mo, ^{103}Rh, ^{105}Pd, ^{109}Ag, ^{111}Cd, ^{114}Sn, ^{117}Sn, ^{118}Sn, ^{119}Sn, ^{124}Te, ^{125}Te, ^{126}Te, ^{127}I, ^{130}Ba, ^{132}Ba, ^{134}Ba, ^{135}Ba, ^{139}La, ^{140}Ce, ^{141}Pr, ^{143}Nd, ^{145}Nd, ^{147}Sm, ^{149}Sm, ^{151}Eu, ^{153}Eu, ^{155}Gd, ^{158}Dy, ^{159}Tb, ^{164}Er, ^{165}Ho, ^{167}Er, ^{169}Tm, ^{171}Yb, ^{172}Yb, ^{175}Lu, ^{177}Hf, ^{178}Hf
Mass spectrometry after chemical separation of single elements	Nearly all nuclides except those with very low contents (see Table 2 in the Appendix).

Analytical technique	Nuclides measurable
Mass spectrometry with on-line chemical separations	Procedures are under development at the ZCH.
Gamma-ray spectrometry without chemical pre-treatment (instrumental gamma-ray spectrometry)	^{133}Ba, ^{143}Pm, ^{153}Gd, ^{172}Hf, ^{172}Lu, ^{173}Lu, ^{174}Lu, and ^{182}Ta.
Gamma-ray spectrometry after chemical separation of highly active radionuclides (e.g. all or some of those mentioned in the previous rubric).	^{54}Mn, ^{57}Co, ^{60}Co, ^{65}Zn, ^{68}Ga, ^{75}Se, ^{88}Y, ^{88}Zr, ^{101}Rh, ^{102m}Rh, ^{102}Rh, ^{139}Ce, ^{144}Pm, ^{146}Pm, ^{149}Eu, ^{150m}Eu, ^{151}Gd, ^{152}Eu, and ^{154}Eu.
Gamma-ray spectrometry after chemical separation of the elements	^{42}K, ^{46}Sc, ^{56}Co, ^{58}Co, ^{73}As, ^{85}Sr, ^{94}Nb, ^{95}Zr, ^{101}Rh, ^{109}Cd, ^{110m}Ag, ^{124}Sb, ^{134}Cs, ^{137}Cs, ^{141}Ce, ^{144}Ce, ^{146}Gd, ^{146}Eu, ^{158}Tb, ^{160}Tb, ^{166m}Ho, ^{168}Tm, ^{170}Tm, ^{175}Hf
Low-level gamma-ray spectrometry after chemical separation of the elements	^{59}Fe, ^{92}Nb, ^{98}Tc, ^{105}Ag, ^{121}Te, ^{109}Cd, ^{169}Yb,
Low-energy photon spectrometry after chemical separation of the elements	^{41}Ca, ^{49}V, ^{55}Fe, ^{59}Ni, ^{68}Ge, ^{73}As, ^{83}Rb, ^{91}Nb, ^{93m}Nb, ^{93}Mo, ^{109}Cd, ^{113}Sn, ^{119m}Sn, ^{125}I, ^{131}Cs, ^{145}Sm, ^{145}Pm, ^{157}Tb, ^{159}Dy, ^{170}Tm, ^{181}W
Liquid scintillation spectrometry (LSC) after chemical separation of the elements	^{45}Ca, ^{63}Ni, ^{90}Sr, ^{93m}Nb, ^{90}Y, ^{107}Pd, ^{123}Sn, ^{147}Pm, ^{151}Sm, ^{171}Tm, ^{145}Sm, ^{145}Pm, ^{157}Tb, ^{159}Dy, ^{170}Tm. A number of the nuclides listed in the previous rubric (LEP) may also be measured with LSC.
Alpha-spectrometry after chemical separation of the elements	^{148}Gd, ^{150}Gd, ^{154}Dy.

Appendix B. Table 2 - Spallation products and analytical methods for their determination

B.1 Explanatory notes

Column 1 - Nuclide

Column 2 - Half-life

Column 3 - Amount in the target

Weights valid for 1 February 1995. Most data are taken from the printout of the calculations at RAL. They are marked by an asterisk. Values without * were calculated from the activities given in the next column by Equation 1 re-arranged for *m*.

Column 4 - Activity in the target

Activities valid for 1 February 1995. Note that the values are given in TBq = 10^{12} Bq. Most data are calculated from the weights by Equation 1. Data with an asterisk were taken from the printout of the calculations at RAL. Activities of short-lived daughter products were equated with those of their long-lived predecessors.

Column 5 - Mean contents

Weights of the nuclides per gram target, valid for 1 April 1997. They are calculated by Equation 2 from the data in Column 3. Amounts contributed by the decay of predecessors are added to these values.

Column 6 - Mean specific activities

Activities of the nuclides per gram target, valid for 1 April 1997. They are calculated by Equation 1 from the data in Column 5, except with short-lived daughter nuclides, for which they were calculated from the activities of their predecessors.

Column 7 - Radiations

Gamma-radiation

If the nuclide emits readily measurable γ-lines these are preferably given, because this is the counting technique usually easiest to apply. One or two γ-lines are quoted. They are not always the most intensive ones, i.e. a line at a high energy may be preferred to a stronger line at a lower energy. Energies are in keV and intensities in % (number of photons per 100 decays), the latter written in italics. Only rounded values are given. More accurate values may be found in the appropriate literature (e.g. [6,7]).

X-rays

are mentioned, if the γ- and β-radiation is too weak to be measured. The intensities given are the sums of those of the $K_{\alpha 1}$-, $K_{\alpha 2}$-, $K_{\beta 1}$- and $K_{\beta 2}$-lines. X-rays and the Auger electrons emitted in connection with them can be measured by LSC but nuclides cannot usually be distinguished by their LSC spectra. If low-energy photon spectrometry is applied, nuclides may be distinguished if their atomic numbers and thus their X-ray energies are sufficiently different.

Beta radiation

is mentioned if γ-radiation is not emitted or is too weak to be measured. The maximum β-energy of the most prominent branch is given. Nuclides with higher energies have higher counting yields with LSC and this is nearly 100% for nuclides with $E_{\beta max}$>200 keV.

Alpha-radiation
is emitted by some spallation products in the rare earth elements. It is not certain whether their decay properties are sufficiently well known to use α-spectrometry for their determination.

Column 8 - Analytical techniques

All analytical techniques mentioned here, except instrumental γ-ray spectrometry (IGS), require a chemical treatment of the sample and this fact is not explicitly stated with the entries in Column 8.

Some remarks have to be made on the following estimates of the suitabilities of analytical techniques:

- The estimates are only valid for samples having at least the "mean" contents or activities as listed in Columns 5 or 6.
- The blind or background values of nuclides caused by the impurities in the tantalum present before it was irradiated in the ISIS can essentially influence the limits of determination and the accuracies (see Section 4.2).
- Some radionuclides amongst the spallation products are probably not well investigated with respect to their decay properties (e.g. half-lives, γ-ray energies and intensities, X-ray energies and intensities) so that the results, for the calculation of which these parameters are required, may not be very accurate.
- Line interferences in γ- and X-ray-spectrometry have not always been considered and may reduce the suitability of the techniques with some nuclides.

The meanings of the abbreviations used are as follows:

IGS
Instrumental γ-spectrometry without radiochemical separation is applicable but may be near its limit of determination. Pre-experiments are not necessary, because the suitability is immediately established, when IGS is applied, which will be done with every sample.

IGS +
Instrumental γ-spectrometry without radiochemical separation is applicable and there is a good chance of obtaining reliable results.

IGS -
Instrumental γ-spectrometry without radiochemical separation has probably no chance, because, in the presence of other radionuclides with much higher activities, the activities are too low for detection and determination.

GS
Gamma-ray-spectrometry after radiochemical separation is applicable, but may be near its limit of determination. Pre-experiments are required.

GS +
Gamma-ray-spectrometry after radiochemical separation is applicable, and has a good chance of yielding reliable results.

GS -
Gamma-ray-spectrometry after radiochemical separation does not have a good chance and the development of appropriate radiochemical separation procedures will be justified only if the knowledge of the spallation yield is very important for understanding the spallation process.

LSC

Liquid scintillation counting after radiochemical separation is suitable, but pre-experiments are necessary to check whether there are interferences from other nuclides of the same or other inseparable elements.

LSC +

Liquid scintillation counting after radiochemical separation is suitable and other nuclides of the same or other inseparable elements will presumably not interfere.

LSC -

Liquid scintillation counting after radiochemical separation does not have a good chance and complicated separation procedures will be necessary, the development of which will be justified only if the knowledge of the spallation yield of the nuclide concerned is very important for understanding the spallation process.

LEP

Low-energy photon spectrometry after radiochemical separation is suitable, but pre-experiments are necessary to check whether there are interferences from other nuclides of the same or other inseparable elements with X-ray spectra of similar energies.

LEP +

Low-energy photon spectrometry after radiochemical separation is suitable and has a good chance of yielding reliable results.

LEP -

Low-energy photon spectrometry after radiochemical separation does not have a good chance and complicated separation procedures will be necessary, the development of which will be justified only, if the knowledge of the spallation yield of the nuclide concerned is very important for understanding the spallation process.

MS

Mass spectrometry with inductively coupled plasma source (ICP-MS) after radiochemical separation of the element to which the nuclide belongs is suitable but the concentrations may be near the determination limits of the technique. Pre-experiments may be necessary.

MS +

ICP-MS after radiochemical separation is suitable and has a good chance of providing reliable results.

MS -

ICP-MS after radiochemical separation does not have a good chance and complicated separation procedures will be necessary, the development of which will be justified only if the knowledge of the spallation yield of the nuclide concerned is very important for understanding the spallation process.

Column 9 - Comments

For some nuclides, marked with "+", more detailed considerations about the applicability of analytical methods are given at the end of the table.

B.2 Table 2 - Spallation products and analytical methods for their determination

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Comments (see end of table)
^{35}Cl	stable	2.30×10^{-5}*	0	7.67×10^{-10}	0		MS -	
^{40}K	1.28×10^{9} y	2.63×10^{-5}*	6.80×10^{-12}	8.77×10^{-10}	2.27×10^{-4}	γ 1461 *11*	GS - MS -	+
^{40}Ar	stable	5.26×10^{-5}*	0	1.75×10^{-9}	0		MS	+
^{40}Ca	stable	2.63×10^{-5}*	0	8.77×10^{-10}	0		MS -	+
^{41}K	stable	5.40×10^{-5}*	0	1.80×10^{-9}	0		MS	+
^{41}Ca	1.03×10^{5} y	5.39×10^{-5}*	1.69×10^{-7}	1.80×10^{-9}	$5.63\times10^{+0}$	X *12*	MS LSC - LEP -	
^{42}Ar	32.9 y	2.63×10^{-5}*	2.52×10^{-4}	8.38×10^{-10}	$8.02\times10^{+3}$	β 600	?	+
^{42}K	12.38 h	1.13×10^{-21}	2.52×10^{-4}	3.60×10^{-14}	$8.02\times10^{+3}$	γ 1525 *18*	GS +	+
^{42}Ca	stable	1.12×10^{-4}*	0	3.73×10^{-9}	0		MS	
^{43}Ca	stable	1.12×10^{-4}*	0	3.73×10^{-9}	0		MS	
^{44}Ca	stable	1.16×10^{-4}*	0	3.87×10^{-9}	0		MS	
^{45}Ca	162.7 d	6.46×10^{-6}*	4.26×10^{-3}	7.47×10^{-12}	$4.93\times10^{+3}$	β 255	LSC +	+

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Com-ments (see end of table)
^{45}Sc	stable	1.42×10^{-4}*	0	4.73×10^{-9}	0		MS	
^{46}Ca	stable	6.05×10^{-5}*	0	2.02×10^{-9}	0		MS	
^{46}Sc	83.81 d	8.14×10^{-7}	1.02×10^{-3}*	3.98×10^{-14}	$4.98\times10^{+1}$	γ 889 *100* γ 1121 *100*	GS + IGS -	+
^{46}Ti	stable	8.99×10^{-5}*	0	3.00×10^{-9}	0		MS	
^{47}Ti	stable	2.52×10^{-4}*	0	8.40×10^{-9}	0		MS	
^{48}Ti	stable	9.32×10^{-5}*	0	3.11×10^{-9}	0		MS	
^{49}Ti	stable	2.74×10^{-4}*	0	9.13×10^{-9}	0		MS	
^{49}V	337 d	4.09×10^{-5}*	1.20×10^{-2}	2.69×10^{-10}	$7.87\times10^{+4}$	X *19*	LSC +	+
^{50}Ti	stable	1.63×10^{-4}*	0	5.43×10^{-9}	0		MS	
^{50}V	stable	1.30×10^{-4}*	0	4.33×10^{-9}	0		MS	
^{51}V	stable	3.93×10^{-4}*	0	1.31×10^{-8}	0		MS	
^{51}Cr	27.7 d	5.38×10^{-8}	1.84×10^{-4}*	4.78×10^{-21}	1.63×10^{-5}	γ 320 *10*	GS -	

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Com-ments (see end of table)
^{52}Cr	stable	4.80×10^{-4}*	0	1.60×10^{-8}	0		MS	
^{53}Cr	stable	2.36×10^{-4}*	0	7.87×10^{-9}	0		MS	
^{53}Mn	3.7×10^{6} y	1.66×10^{-4}*	1.12×10^{-8}	5.53×10^{-9}	3.73×10^{-1}	X *24*	MS	+
^{54}Cr	stable	3.61×10^{-4}*	0	1.20×10^{-8}	0		MS	
^{54}Mn	312.2 d	9.88×10^{-5}*	2.83×10^{-2}	5.71×10^{-10}	$1.64\times10^{+5}$	γ 835 *100*	IGS GS +	
^{54}Fe	stable	3.55×10^{-5}*	0	1.18×10^{-9}	0		MS	
^{55}Mn	stable	3.51×10^{-4}*	0	1.17×10^{-8}	0		MS	
^{55}Fe	2.73 y	8.43×10^{-5}*	7.43×10^{-3}	1.62×10^{-9}	$1.43\times10^{+5}$	X *27*	LSC LEP	+
^{56}Fe	stable	5.80×10^{-4}*	0	1.93×10^{-8}	0		MS	
^{56}Co	77.3 d	1.68×10^{-6}*	1.88×10^{-3}	4.74×10^{-14}	$5.29\times10^{+1}$	γ 847 *100* γ 1238 *67*	IGS - GS +	
^{57}Fe	stable	5.95×10^{-4}*	0	1.98×10^{-8}	0		MS	
^{57}Co	271.8 d	7.53×10^{-5}*	2.35×10^{-2}	3.36×10^{-10}	$1.05\times10^{+5}$	γ 122 *86* γ 136 *11*	IGS GS +	

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Com-ments (see end of table)
^{58}Fe	stable	4.90×10^{-4}*	0	1.63×10^{-8}	0		MS	
^{58}Co	70.88 d	5.83×10^{-6}*	6.85×10^{-3}	8.66×10^{-14}	$1.02\times10^{+2}$	γ 811 *100*	IGS - GS +	
^{58}Ni	stable	1.13×10^{-4}*	0	3.77×10^{-9}	0		MS	
^{59}Fe	44.51 d	2.55×10^{-7}	4.70×10^{-4}*	3.93×10^{-17}	7.22×10^{-2}	γ 1099 *57* γ 1292 *43*	IGS - GS	
^{59}Co	stable	6.13×10^{-4}*	0	2.04×10^{-8}	0		MS	
^{59}Ni	76000 y	1.15×10^{-4}*	3.39×10^{-7}	3.83×10^{-9}	$1.13\times10^{+1}$	X *33*	LSC - LEP	
^{60}Fe	1.5×10^{6} y	1.16×10^{-4}*	1.71×10^{-8}	3.87×10^{-9}	5.68×10^{-1}	γ 59 *2*	MS GS -	+
^{60}Co	5.271 y	1.17×10^{-4}*	4.89×10^{-3}	2.94×10^{-9}	$1.23\times10^{+5}$	γ 1173 *100* γ 1333 *100*	IGS GS +	+
^{60}Ni	stable	8.50×10^{-4}*	0	2.83×10^{-8}	0		MS	
^{61}Ni	stable	9.44×10^{-4}*	0	3.15×10^{-8}	0		MS	
^{62}Ni	stable	1.79×10^{-3}*	0	5.97×10^{-8}	0		MS	
^{63}Ni	100 y	1.61×10^{-4}*	3.38×10^{-4}	5.29×10^{-9}	$1.11\times10^{+4}$	β 66	MS LSC	+

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Com-ments (see end of table)
^{63}Cu	stable	1.26×10^{-3}*	0	4.20×10^{-8}	0		MS	
^{64}Ni	stable	5.13×10^{-4}*	0	1.71×10^{-8}	0		MS	
^{64}Zn	stable	1.44×10^{-3}*	0	4.80×10^{-8}	0		MS	
^{65}Cu	stable	1.24×10^{-3}*	0	4.13×10^{-8}	0		MS	
^{65}Zn	243.8 d	2.34×10^{-4}*	7.13×10^{-2}	8.28×10^{-10}	$2.52\times10^{+5}$	γ 1116 *51*	IGS GS +	
^{66}Zn	stable	2.26×10^{-3}*	0	7.53×10^{-8}	0		MS	
^{67}Zn	stable	2.83×10^{-3}*	0	9.43×10^{-8}	0		MS	
^{68}Zn	stable	1.89×10^{-3}*	0	6.30×10^{-8}	0		MS	
^{68}Ge	270.8 d	1.54×10^{-4}*	4.04×10^{-2}	6.81×10^{-10}	$1.79\times10^{+5}$	X *34*	LSC LEP	+
^{68}Ga	1.13 h	2.68×10^{-20}	4.04×10^{-2}	1.18×10^{-13}	$1.79\times10^{+5}$	γ 1077 *3*	GS	+
^{69}Ga	stable	2.64×10^{-3}*	0	8.80×10^{-8}	0		MS	
^{70}Zn	stable	9.26×10^{-5}*	0	3.09×10^{-9}	0		MS	

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Com-ments (see end of table)
^{70}Ge	stable	4.36×10^{-3}*	0	1.45×10^{-7}	0		MS +	
^{71}Ga	stable	3.04×10^{-3}*	0	1.01×10^{-7}	0		MS +	
^{72}Ge	stable	4.19×10^{-3}*	0	1.40×10^{-7}	0		MS +	
^{73}Ge	stable	1.90×10^{-4}*	0	6.33×10^{-9}	0		MS	
^{73}As	80.3 d	1.11×10^{-4}*	9.15×10^{-2}	4.08×10^{-12}	$3.36\times10^{+3}$	γ 53 *11*	IGS - GS	+
^{73}Se	7.1 h	$1.60\times10^{+0}$*	$3.58\times10^{+5}$	0.00E+00	0		?	+
^{74}Ge	stable	3.32×10^{-4}*	0	1.11×10^{-8}	0		MS	
^{74}As	17.78 d	2.51×10^{-9}	9.21×10^{-6}*	0.00E+00	0	γ 596 *60*	GS -	+
^{74}Se	stable	3.84×10^{-3}*	0	1.28×10^{-7}	0		MS +	
^{75}As	stable	3.53×10^{-3}*	0	1.18×10^{-7}	0		MS +	
^{75}Se	119.78 d	1.86×10^{-4}*	1.00×10^{-1}	6.45×10^{-11}	$3.47\times10^{+4}$	γ 279 *25* γ 401 *12*	IGS GS +	
^{76}Ge	stable	5.00×10^{-5}*	0	1.67×10^{-9}	0		MS	

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Com-ments (see end of table)
^{76}Se	stable	6.24×10^{-3}*	0	2.08×10^{-7}	0		MS +	
^{77}Se	stable	7.03×10^{-3}*	0	2.34×10^{-7}	0		MS +	
^{78}Se	stable	2.09×10^{-3}*	0	6.97×10^{-8}	0		MS	
^{78}Kr	stable	6.10×10^{-3}*	0	2.03×10^{-7}	0		?	+
^{79}Se	6.5×10^{4} y	5.19×10^{-5}*	1.34×10^{-7}	1.73×10^{-9}	$4.46\times10^{+0}$	β 160	MS	+
^{79}Br	stable	6.58×10^{-3}*	0	2.19×10^{-7}	0		MS +	
^{80}Se	stable	2.16×10^{-4}*	0	7.20×10^{-9}	0		MS	
^{80}Kr	stable	9.38×10^{-3}*	0	3.13×10^{-7}	0		?	
^{81}Br	stable	3.07×10^{-4}*	0	1.02×10^{-8}	0		MS +	
^{81}Kr	2.15×10^{5} y	8.07×10^{-3}*	6.13×10^{-6}	2.69×10^{-7}	$2.04\times10^{+2}$	X *53*	?	+
^{82}Kr	stable	1.18×10^{-2}*	0	3.93×10^{-7}	0		?	
^{82}Sr	25.36 d	8.44×10^{-7}	1.96×10^{-3}*	1.21×10^{-20}	2.82×10^{-5}	X *58*	LEP -	+

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Comments (see end of table)
^{82}Rb	1.27 m	2.93×10^{-23}	1.96×10^{-3}	4.21×10^{-25}	2.82×10^{-5}	γ 777 *13*	GS -	+
^{83}Kr	stable	1.15×10^{-2}*	0	3.83×10^{-7}	0		?	+
^{83}Rb	86.2 d	3.28×10^{-4}*	2.22×10^{-1}	1.92×10^{-11}	$1.30\times10^{+4}$	X *68*	LSC +	
^{84}Kr	stable	1.85×10^{-3}*	0	6.17×10^{-8}	0		?	+
^{84}Rb	32.9 d	1.26×10^{-6}*	2.20×10^{-3}	2.54×10^{-18}	4.43×10^{-3}	X *41*	LSC - LEP -	+
^{84}Sr	stable	1.29×10^{-2}*	0	4.30×10^{-7}	0		MS +	
^{85}Kr	10.73 y	7.93×10^{-5}*	1.15×10^{-3}	2.30×10^{-9}	$3.33\times10^{+4}$	β 690	?	+
^{85}Rb	stable	1.50×10^{-2}*	0	5.00×10^{-7}	0		MS +	
^{85}Sr	64.84 d	1.83×10^{-4}*	1.60×10^{-1}	1.33×10^{-12}	$1.16\times10^{+3}$	γ 514 *99*	IGS GS +	
^{86}Kr	stable	5.65×10^{-5}*	0	1.88×10^{-9}	0		?	+
^{86}Rb	18.65 d	1.09×10^{-8}	3.27×10^{-5}*	6.66×10^{-26}	2.01×10^{-10}	γ 1077 *9*	GS -	+
^{86}Sr	stable	2.41×10^{-2}*	0	8.03×10^{-7}	0		MS +	

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Comments (see end of table)
^{87}Rb	stable	4.41×10^{-4}*	0	1.47×10^{-8}	0		MS	
^{87}Sr	stable	2.93×10^{-2}*	0	9.77×10^{-7}	0		MS +	
^{88}Sr	stable	4.71×10^{-2}*	0	1.57×10^{-6}	0		MS +	
^{88}Y	106.6 d	3.94×10^{-3}*	$2.03\times10^{+0}$	7.77×10^{-10}	$4.00\times10^{+5}$	γ 898 *93* γ 1836 *99*	IGS GS +	
^{88}Zr	83.4 d	8.88×10^{-4}*	5.85×10^{-1}	4.20×10^{-11}	$2.77\times10^{+4}$	γ 393 *97*	IGS GS +	+
^{89}Sr	50.52 d	8.52×10^{-6}*	9.16×10^{-3}	5.65×10^{-15}	$6.07\times10^{+0}$	β 1490	LSC -	+
^{89}Y	stable	6.88×10^{-2}*	0	2.29×10^{-6}	0		MS +	
^{90}Sr	29.1 y	3.76×10^{-4}*	1.90×10^{-3}	1.19×10^{-8}	$6.01\times10^{+4}$	β 546	LSC +	+
^{90}Y	2.67 d	9.45×10^{-20}	1.90×10^{-3}	2.99×10^{-12}	$6.01\times10^{+4}$	β 2288	LSC +	+
^{90}Zr	stable	4.47×10^{-2}*	0	1.49×10^{-6}	0		MS +	
^{91}Y	58.5 d	5.80×10^{-5}*	5.26×10^{-2}	1.68×10^{-13}	$1.53\times10^{+2}$	β 1545	GS - LSC -	+
^{91}Zr	stable	2.10×10^{-2}*	0	7.00×10^{-7}	0		MS +	

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Comments (see end of table)
^{91}Nb	680.0 y	1.54×10^{-3}*	3.29×10^{-4}	5.12×10^{-8}	$1.10\times10^{+4}$	X *63*	MS LSC LEP	+
^{92}Zr	stable	1.60×10^{-2}*	0	5.33×10^{-7}	0		MS +	
^{92}Nb	3.6×10^{7} y	8.35×10^{-4}*	3.34×10^{-9}	2.78×10^{-8}	1.11×10^{-1}	γ 561 *100* γ 934 *100*	MS GS	+
^{92}Mo	stable	2.39×10^{-4}*	0	7.97×10^{-9}	0		MS	
^{93}Zr	1.5×10^{6} y	9.64×10^{-3}*	9.14×10^{-7}	3.21×10^{-7}	$3.05\times10^{+1}$	β 60	MS + LSC -	+
^{93m}Nb	13.6 y	1.60×10^{-8}	1.67×10^{-7}*	4.77×10^{-13}	$4.99\times10^{+0}$	X *11*	LSC - LEP	+
^{93}Nb	stable	6.70×10^{-4}*	0	2.23×10^{-8}	0		MS	
^{93}Mo	3500 y	4.14×10^{-4}*	1.68×10^{-5}	1.38×10^{-8}	$5.61\times10^{+2}$	X *73*	MS LSC +	+
^{94}Zr	stable	7.36×10^{-3}*	0	2.45×10^{-7}	0		MS +	
^{94}Nb	20000 y	2.94×10^{-4}*	2.07×10^{-6}	9.80×10^{-9}	$6.90\times10^{+1}$	γ 703 *100* γ 871 *100*	MS GS +	
^{94}Mo	stable	4.15×10^{-4}*	0	1.38×10^{-8}	0		MS	
^{95}Zr	64.02 d	2.07×10^{-5}*	1.64×10^{-2}	1.35×10^{-13}	$1.07\times10^{+2}$	γ 724 *44* γ 757 *55*	GS +	+

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Com-ments (see end of table)
^{95m}Nb	3.61 d	1.45×10^{-8}	2.04×10^{-4}*	7.22×10^{-17}	$1.02\times10^{+0}$	γ 236 *25*	GS +	+
^{95}Nb	34.97 d	2.25×10^{-5}*	3.27×10^{-2}	1.62×10^{-13}	$2.35\times10^{+2}$	γ 766 *100*	GS +	+
^{95}Mo	stable	2.24×10^{-3}*	0	7.47×10^{-8}	0		MS	
^{96}Zr	stable	6.31×10^{-4}*	0	2.10×10^{-8}	0		MS	
^{96}Mo	stable	2.52×10^{-4}*	0	8.40×10^{-9}	0		MS	
^{96}Ru	stable	1.86×10^{-4}*	0	6.20×10^{-9}	0		MS	
^{97}Mo	stable	2.52×10^{-4}*	0	8.40×10^{-9}	0		MS	
^{97}Tc	2.6×10^{6} y	3.28×10^{-4}*	1.72×10^{-8}	1.09×10^{-8}	5.74×10^{-1}	X *67*	MS LSC -	+
^{98}Mo	stable	2.58×10^{-4}*	0	8.60×10^{-9}	0		MS	
^{98}Tc	4.2×10^{6} y	1.90×10^{-4}*	6.11×10^{-9}	6.33×10^{-9}	2.04×10^{-1}	γ 652 *100* γ 745 *100*	MS GS	+
^{98}Ru	stable	2.55×10^{-4}*	0	8.50×10^{-9}	0		MS	
^{99}Tc	2.13×10^{5} y	1.96×10^{-4}*	1.23×10^{-7}	6.53×10^{-9}	$4.10\times10^{+0}$	β 290	MS LSC +	+

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Com-ments (see end of table)
^{99}Rh	16.0 d	1.96×10^{-6}*	5.99×10^{-3}	0.00E+00	0	γ 353 *33* γ 529 *40*	GS -	+
^{99}Ru	stable	5.13×10^{-4}*	0	1.71×10^{-8}	0		MS	
^{100}Mo	stable	1.31×10^{-4}*	0	4.37×10^{-9}	0		MS	
^{100}Ru	stable	1.99×10^{-4}*	0	6.63×10^{-9}	0		MS	
^{101}Ru	stable	1.80×10^{-4}*	0	6.00×10^{-9}	0		MS	
^{101}Rh	3.3 y	8.61×10^{-5}*	3.42×10^{-3}	1.82×10^{-9}	$7.24\times10^{+4}$	γ 127 *73* γ 198 *71*	GS + IGS MS	
^{102}Ru	stable	2.78×10^{-4}*	0	9.27×10^{-9}	0		MS	
^{102m}Rh	207.0 d	1.21×10^{-4}*	2.77×10^{-2}	2.87×10^{-10}	$6.57\times10^{+4}$	γ 475 *46*	IGS GS +	+
^{102}Rh	2.9 y	1.21×10^{-4}*	5.41×10^{-3}	2.41×10^{-9}	$1.08\times10^{+5}$	γ 475 *95* γ 631 *56*	IGS GS +	+
^{102}Pd	stable	2.65×10^{-4}*	0	8.83×10^{-9}	0		MS	
^{103}Rh	stable	4.71×10^{-4}*	0	1.57×10^{-8}	0		MS	
^{104}Ru	stable	6.85×10^{-5}*	0	2.28×10^{-9}	0		MS	

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Com-ments (see end of table)
^{104}Pd	stable	2.73×10^{-4}*	0	9.10×10^{-9}	0		MS	
^{105}Pd	stable	6.91×10^{-4}*	0	2.30×10^{-8}	0		MS	
^{105}Ag	41.3 d	9.69×10^{-7}	1.08×10^{-3}*	5.73×10^{-17}	6.39×10^{-2}	γ 281 *31* γ 345 *42*	GS	+
^{106}Pd	stable	2.09×10^{-4}*	0	6.97×10^{-9}	0		MS	
^{106}Cd	stable	2.75×10^{-4}*	0	9.17×10^{-9}	0		MS	
^{107}Pd	6.5×10^{6} y	2.78×10^{-4}*	5.29×10^{-9}	9.27×10^{-9}	1.76×10^{-1}	β 40	MS LSC	
^{107}Ag	stable	3.50×10^{-4}*	0	1.17×10^{-8}	0		MS	
^{108}Pd	stable	7.58×10^{-5}*	0	2.53×10^{-9}	0		MS	
^{108}Cd	stable	4.18×10^{-4}*	0	1.39×10^{-8}	0		MS	
^{109}Ag	stable	7.17×10^{-5}*	0	2.39×10^{-9}	0		MS	
^{109}Cd	462 d	1.04×10^{-4}*	9.98×10^{-3}	1.06×10^{-9}	$1.02\times10^{+5}$	γ 88 *4*	IGS GS +	
^{109}In	4.2 h	4.03×10^{-8}	1.02×10^{-2}*	0.00E+00	0	γ 203 *73*	?	+

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Com-ments (see end of table)
^{110}Pd	stable	1.71×10^{-7}*	0	5.70×10^{-12}	0		?	
^{110m}Ag	249.8 d	1.44×10^{-5}*	2.53×10^{-3}	5.38×10^{-11}	$9.45\times10^{+3}$	γ 658 *95* γ 885 *73*	IGS GS +	
^{110}Cd	stable	4.89×10^{-4}*	0	1.63×10^{-8}	0		MS	
^{111}Cd	stable	6.76×10^{-4}*	0	2.25×10^{-8}	0		MS	
^{112}Cd	stable	7.39×10^{-4}*	0	2.46×10^{-8}	0		MS	
^{112}Sn	stable	5.96×10^{-4}*	0	1.99×10^{-8}	0		MS	
^{113}Cd	stable	7.43×10^{-4}*	0	2.48×10^{-8}	0		MS	
^{113}In	stable	4.94×10^{-4}*	0	1.65×10^{-8}	0		MS	
^{113}Sn	115.1 d	8.35×10^{-6}*	3.10×10^{-3}	2.40×10^{-12}	$8.93\times10^{+2}$	X *98*	LSC LEP	
^{114}Sn	stable	8.28×10^{-4}*	0	2.76×10^{-8}	0		MS	
^{115m}Cd	44.6 d	2.12×10^{-8}	2.00×10^{-5}*	3.35×10^{-18}	3.15×10^{-3}	γ 934 *2*	GS - LSC -	+
^{115}In	stable	2.98×10^{-4}*	0	9.93×10^{-9}	0		MS	

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Comments (see end of table)
^{115}Sn	stable	5.28×10^{-4}*	0	1.76×10^{-8}	0		MS	
^{116}Cd	stable	7.63×10^{-5}*	0	2.54×10^{-9}	0		MS	
^{116}Sn	stable	8.42×10^{-4}*	0	2.81×10^{-8}	0		MS	
^{117}Sn	stable	8.40×10^{-4}*	0	2.80×10^{-8}	0		MS	
^{118}Sn	stable	9.83×10^{-4}*	0	3.28×10^{-8}	0		MS	
^{119}Sn	stable	1.10×10^{-3}*	0	3.67×10^{-8}	0		MS	
^{119m}Sn	293 d	3.23×10^{-7}	4.48×10^{-5}*	1.67×10^{-12}	$2.31\times10^{+2}$	X *90*	LSC	+
^{120}Sn	stable	2.33×10^{-4}*	0	7.77×10^{-9}	0		MS	
^{120}Te	stable	7.97×10^{-4}*	0	2.66×10^{-8}	0		MS	
^{121}Sn	stable	1.11×10^{-3}*	0	3.70×10^{-8}	0		MS	
^{121}Sb	stable	8.90×10^{-4}*	0	2.97×10^{-8}	0		MS	
^{121}Te	154 d	1.69×10^{-10}*	4.38×10^{-8}	1.62×10^{-16}	4.19×10^{-2}	γ 212 *81*	GS	

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Comments (see end of table)
^{122}Sn	stable	not calc.	not calc.	not calc.	not calc.		MS	
^{122}Te	stable	9.20×10^{-4}*	0	3.07×10^{-8}	0		MS	
^{123}Sn	129.2 d	5.71×10^{-6}*	1.74×10^{-3}	2.76×10^{-12}	$8.40\times10^{+2}$	β 1420	LSC	+
^{123}Sb	stable	7.52×10^{-5}*	0	2.51×10^{-9}	0		MS	
^{123}Te	1.3×10^{13} y	1.05×10^{-3}*	8.69×10^{-15}	3.50×10^{-8}	2.90×10^{-7}		MS	
^{124}Sb	60.2 d	not calc.	not calc.	not calc.	not calc.	γ 603 *98* γ 1690 *47*	GS	
^{124}Te	stable	3.36×10^{-4}*	0	1.12×10^{-8}	0		MS	
^{124}Xe	stable	1.29×10^{-3}*	0	4.30×10^{-8}	0		?	
^{125}Te	stable	1.97×10^{-3}*	0	6.57×10^{-8}	0		MS	
^{125}I	60.1 d	1.99×10^{-5}*	1.28×10^{-2}	7.41×10^{-14}	$4.77\times10^{+1}$	X *140*	LSC	+
^{126}Te	stable	4.59×10^{-5}*	0	1.53×10^{-9}	0		MS	
^{126}Xe	stable	2.50×10^{-3}*	0	8.33×10^{-8}	0		?	

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Comments (see end of table)
^{127}I	stable	3.49×10^{-3}*	0	1.16×10^{-7}	0		MS +	
^{127}Xe	36.4 d	4.58×10^{-6}*	4.79×10^{-3}	4.56×10^{-17}	4.76×10^{-2}	γ 172 *24* γ 203 *68*	?	+
^{128}Xe	stable	4.26×10^{-3}*	0	1.42×10^{-7}	0		?	+
^{129m}Te	33.6 d	4.04×10^{-9}*	4.50×10^{-6}	1.15×10^{-20}	1.28×10^{-5}	γ 695 *3*	GS -	+
^{129}Te	1.16 h	5.81×10^{-24}	4.50×10^{-6}	1.65×10^{-23}	1.28×10^{-5}	γ 459 *8*	GS -	+
^{129}I	1.57×10^{7} y	1.70×10^{-4}*	1.11×10^{-9}	5.67×10^{-9}	3.70×10^{-2}	β 150	MS	+
^{129}Xe	stable	3.72×10^{-3}*	0	1.24×10^{-7}	0		?	+
^{130}Xe	stable	2.48×10^{-3}*	0	8.27×10^{-8}	0		?	
^{130}Ba	stable	4.40×10^{-3}*	0	1.47×10^{-7}	0		MS +	
^{131}Ba	11.7 d	7.27×10^{-12}*	2.29×10^{-8}	0.00E+00	0	γ 216 *20* γ 496 *44*	GS -	+
^{131}Cs	9.69 d	not calc.	not calc.	not calc.	not calc.	X *74*	LEP -	+
^{131}Xe	stable	7.11×10^{-3}*	0	2.37×10^{-7}	0		?	+

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Comments (see end of table)
^{132}Xe	stable	not calc.	not calc.	not calc.	not calc.		?	+
^{132}Ba	stable	8.47×10^{-3}*	0	2.82×10^{-7}	0		MS +	
^{133}Cs	stable	1.05×10^{-3}*	0	3.50×10^{-8}	0		MS	
^{133}Ba	10.53 y	6.70×10^{-3}*	6.33×10^{-2}	1.94×10^{-7}	$1.83\times10^{+6}$	γ 303 *18* γ 356 *62*	IGS + GS + MS +	
^{134}Xe	stable	not calc.	not calc.	not calc.	not calc.		?	+
^{134}Cs	2.065 y	not calc.	not calc.	not calc.	not calc.	γ 605 *98* γ 796 *85*	GS	
^{134}Ba	stable	1.10×10^{-2}*	0	3.67×10^{-7}	0		MS +	
^{135}Ba	stable	1.18×10^{-2}*	0	3.93×10^{-7}	0		MS +	
^{136}Xe	stable	not calc.	not calc.	not calc.	not calc.		?	+
^{136}Ba	stable	3.53×10^{-4}*	0	1.18×10^{-8}	0		MS +	
^{136}Ce	stable	1.63×10^{-2}*	0	5.43×10^{-7}	0		MS +	
^{137}Cs	30.17 y	not calc.	not calc.	not calc.	not calc.	γ 662 *85*	GS	

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Com-ments (see end of table)
^{137}Ba	stable	not calc.	not calc.	not calc.	not calc.		MS	
^{138}Ba	stable	not calc.	not calc.	not calc.	not calc.		MS	
^{138}La	stable	not calc.	not calc.	not calc.	not calc.		MS	
^{138}Ce	stable	2.52×10^{-2}*	0	8.40×10^{-7}	0		MS +	
^{139}La	stable	2.64×10^{-2}*	0	8.80×10^{-7}	0		MS +	
^{139}Ce	137.6 d	2.28×10^{-3}*	5.76×10^{-1}	1.43×10^{-9}	$3.61\times10^{+5}$	γ 166 *80*	IGS GS + MS	
^{140}Ce	stable	3.26×10^{-2}*	0	1.09×10^{-6}	0		MS +	
^{141}Ce	32.5 d	not calc.	not calc.	not calc.	not calc.	γ 145 *48*	GS	
^{141}Pr	stable	3.51×10^{-2}*	0	1.17×10^{-6}	0		MS +	
^{142}Ce	stable	not calc.	not calc.	not calc.	not calc.		MS	
^{142}Nd	stable	4.33×10^{-2}*	0	1.44×10^{-6}	0		MS +	
^{143}Nd	stable	3.47×10^{-2}*	0	1.16×10^{-6}	0		MS +	

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Com-ments (see end of table)
^{143}Pm	265.0 d	9.22×10^{-3}*	$1.18\times10^{+0}$	3.90×10^{-8}	$4.98\times10^{+6}$	γ 742 *39*	IGS + GS + MS	
^{144}Ce	284.6 d	not calc.	not calc.	not calc.	not calc.	γ 134 *11*	GS	
^{144}Nd	stable	2.19×10^{-3}*	0	7.30×10^{-8}	0		MS	
^{144}Pm	363.0 d	7.97×10^{-4}*	7.37×10^{-2}	5.89×10^{-9}	$5.44\times10^{+5}$	γ 618 *99* γ 697 *100*	IGS + GS +	
^{144}Sm	stable	5.01×10^{-2}*	0	1.67×10^{-6}	0		MS +	
^{145}Sm	340 d	1.50×10^{-2}*	$1.47\times10^{+0}$	1.00×10^{-7}	$9.81\times10^{+6}$	X *142*	MS + LEP	
^{145}Pm	17.7 y	3.82×10^{-2}*	1.97×10^{-1}	1.17×10^{-6}	$6.03\times10^{+6}$	X *78*	MS + LEP	
^{145}Nd	stable	2.85×10^{-3}*	0	9.50×10^{-8}	0		MS	
^{146}Nd	stable	8.22×10^{-5}*	0	2.74×10^{-9}	0		MS	
^{146}Pm	5.53 y	4.18×10^{-4}*	6.85×10^{-3}	1.06×10^{-8}	$1.74\times10^{+5}$	γ 454 *65* γ 747 *34*	IGS GS + MS	+
^{146}Sm	1.03×10^{8} y	6.10×10^{-2}*	5.37×10^{-8}	2.03×10^{-6}	$1.79\times10^{+0}$		MS +	+

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Comments (see end of table)
^{146}Gd	48.3 d	1.74×10^{-4}*	1.19×10^{-1}	7.01×10^{-14}	$4.81\times10^{+1}$	γ 115 *88* γ 155 *47*	IGS GS +	
^{146}Eu	4.57 d	1.65×10^{-17}	1.19×10^{-1}	6.64×10^{-15}	$4.81\times10^{+1}$	γ 634 *82* γ 747 *98*	IGS GS +	
^{147}Pm	2.6234 y	3.22×10^{-4}*	1.10×10^{-2}	6.07×10^{-9}	$2.08\times10^{+5}$	β 224	LSC	
^{147}Sm	1.06×10^{11} y	6.75×10^{-2}*	5.73×10^{-11}	2.25×10^{-6}	1.91×10^{-3}	α 2230	MS +	
^{147}Eu	24.4 d	3.17×10^{-7}*	4.27×10^{-4}	1.95×10^{-21}	2.63×10^{-6}	γ 197 *26* γ 678 *11*	GS -	+
^{148}Nd	stable	not calc.	not calc.	not calc.	not calc.		MS	
^{148}Sm	7.0×10^{14} y	9.16×10^{-3}*	1.17×10^{-15}	3.05×10^{-7}	3.90×10^{-8}	α 1960	MS AS -	
^{148}Eu	54.5 d	5.51×10^{-5}*	3.30×10^{-2}	8.05×10^{-14}	$4.82\times10^{+1}$	γ 550 *99* γ 630 *71*	IGS - GS +	
^{148}Gd	75 y	6.61×10^{-2}*	7.88×10^{-2}	2.16×10^{-6}	$2.57\times10^{+6}$	α 3183	MS +	
^{148}Tb	1.00 h	2.59×10^{-9}*	2.03×10^{-3}	0.00E+00	0	γ 631 *93* γ 784 *100*	?	+
^{149}Sm	stable	7.43×10^{-2}*	0	2.48×10^{-6}	0		MS +	
^{149}Eu	93.1 d	2.85×10^{-3}*	9.93×10^{-1}	2.67×10^{-10}	$9.30\times10^{+4}$	γ 277 *3* γ 328 *4*	IGS GS +	

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Com-ments (see end of table)
^{150}Nd	stable	not calc.	not calc.	not calc.	not calc.		MS	
^{150}Sm	stable	1.88×10^{-4}*	0	6.27×10^{-9}	0		MS	
^{150m}Eu	36.0 y	1.98×10^{-3}*	4.85×10^{-3}	6.33×10^{-8}	$1.55\times10^{+5}$	γ 334 *79* γ 584 *52*	IGS GS +	
^{150}Gd	1.8×10^{6} y	7.51×10^{-2}*	3.68×10^{-6}	2.50×10^{-6}	$1.23\times10^{+2}$	α 2715	MS + AS	
^{151}Sm	90 y	9.76×10^{-5}*	9.50×10^{-5}	3.20×10^{-9}	$3.11\times10^{+3}$	β 55	LSC + MS	
^{151}Eu	stable	8.37×10^{-2}*	0	2.79×10^{-6}	0		MS +	
^{151}Gd	120 d	5.42×10^{-3}*	$1.45\times10^{+0}$	1.89×10^{-9}	$5.05\times10^{+5}$	γ 153 *5* γ 243 *5*	IGS GS +	
^{152}Sm	stable	3.21×10^{-5}*	0	1.07×10^{-9}	0		MS	
^{152}Eu	13.48 y	3.50×10^{-4}*	2.26×10^{-3}	1.04×10^{-8}	$6.74\times10^{+4}$	γ 344 *27* γ 1408 *21*	IGS GS +	
^{152}Gd	1.1×10^{14} y	1.11×10^{-1}*	8.78×10^{-14}	3.70×10^{-6}	2.93×10^{-6}	α 2140	MS + AS	
^{153}Eu	stable	9.12×10^{-2}*	0	3.04×10^{-6}	0		MS +	
^{153}Gd	241.6 d	2.16×10^{-2}*	$2.82\times10^{+0}$	7.49×10^{-8}	$9.79\times10^{+6}$	γ 97 *28* γ 103 *20*	IGS GS +	

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Comments (see end of table)
^{154}Sm	stable	not calc.	not calc.	not calc.	not calc.		MS	
^{154}Eu	8.59 y	8.47×10^{-5}*	8.47×10^{-4}	2.37×10^{-9}	$2.37\times10^{+4}$	γ 723 *20* γ 1274 *36*	IGS GS +	
^{154}Gd	stable	1.06×10^{-2}*	0	3.53×10^{-7}	0		MS +	
^{154}Dy	3.0×10^{6} y	1.22×10^{-1}*	3.49×10^{-6}	4.07×10^{-6}	$1.16\times10^{+2}$	α 2872	MS + AS	
^{155}Eu	4.71 y	not calc.	not calc.	not calc.	not calc.	γ 87 *34* γ 105 *21*	GS	
^{155}Gd	stable	1.40×10^{-1}*	0	4.67×10^{-6}	0		MS +	
^{156}Eu	15.2 d	5.31×10^{-12}*	1.08×10^{-8}	0.00E+00	0	γ 812 *10* γ 1230 *9*	GS -	+
^{156}Gd	stable	2.34×10^{-3}*	0	7.80×10^{-8}	0		MS	
^{156}Dy	stable	1.41×10^{-1}*	0	4.70×10^{-6}	0		MS +	
^{157}Gd	stable	1.65×10^{-3}*	0	5.50×10^{-8}	0		MS	
^{157}Tb	150 y	1.55×10^{-1}*	8.71×10^{-2}	5.12×10^{-6}	$2.87\times10^{+6}$	X *20*	MS + LSC LEP	
^{158}Gd	stable	1.80×10^{-6}*	0	6.00×10^{-11}	0		MS -	

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Comments (see end of table)
^{158}Tb	150 y	2.06×10^{-4}*	1.15×10^{-4}	6.80×10^{-9}	$3.79\times10^{+3}$	γ 944 *43* γ 962 *20*	IGS GS +	
^{158}Dy	stable	1.79×10^{-1}*	0	5.97×10^{-6}	0		MS +	
^{159}Tb	stable	1.89×10^{-1}*	0	6.30×10^{-6}	0		MS +	
^{159}Dy	144.4 d	1.79×10^{-2}*	$3.77\times10^{+0}$	1.35×10^{-8}	$2.84\times10^{+6}$	X *95*	MS LSC LEP	
^{160}Gd	stable	not calc.	not calc.	not calc.	not calc.		MS	
^{160}Tb	72.3 d	not calc.	not calc.	not calc.	not calc.	γ 879 *30* γ 966 *25*	GS	
^{160}Dy	stable	2.23×10^{-1}*	0	7.43×10^{-6}	0		MS +	
^{161}Dy	stable	1.95×10^{-1}*	0	6.50×10^{-6}	0		MS +	
^{162}Dy	stable	3.25×10^{-3}*	0	1.08×10^{-7}	0		MS +	
^{162}Er	stable	2.72×10^{-1}*	0	9.07×10^{-6}	0		MS +	
^{163}Dy	stable	8.13×10^{-3}*	0	2.71×10^{-7}	0		MS +	
^{163}Ho	33.0 y	1.63×10^{-1}*	4.01×10^{-1}	5.19×10^{-6}	$1.28\times10^{+7}$	X *0*	MS + LSC ?	+

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Comments (see end of table)
^{164}Dy	stable	4.47×10^{-4}*	0	1.49×10^{-8}	0		MS	
^{164}Er	stable	3.09×10^{-1}*	0	1.03×10^{-5}	0		MS +	
^{165}Ho	stable	2.66×10^{-1}*	0	8.87×10^{-6}	0		MS +	
^{166m}Ho	1200 y	not calc.	not calc.	not calc.	not calc.	γ 712 *60* γ 810 *64*	GS	
^{166}Er	stable	4.24×10^{-1}*	0	1.41×10^{-5}	0		MS +	
^{167}Er	stable	4.05×10^{-1}*	0	1.35×10^{-5}	0		MS +	
^{168}Er	stable	not calc.	not calc.	not calc.	not calc.		MS	
^{168}Tm	93.1 d	not calc.	not calc.	not calc.	not calc.	γ 198 *49* γ 816 *45*	GS	
^{168}Yb	stable	4.58×10^{-1}*	0	1.53×10^{-5}	0		MS +	
^{169}Tm	stable	2.28×10^{-1}*	0	7.60×10^{-6}	0		MS +	
^{169}Yb	32.03 d	1.56×10^{-4}*	1.39×10^{-1}	2.00×10^{-16}	1.78×10^{-1}	γ 177 *22* γ 198 *35*	GS	+
^{170}Er	stable	6.75×10^{-4}*	0	2.25×10^{-8}	0		MS +	

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Comments (see end of table)
^{170}Tm	128.6 d	2.80×10^{-4}*	6.19×10^{-2}	1.33×10^{-10}	$2.93\times10^{+4}$	γ 84 *3*	IGS GS +	
^{170}Yb	stable	5.74×10^{-1}*	0	1.91×10^{-5}	0		MS +	
^{171}Tm	1.92 y	1.64×10^{-3}*	6.61×10^{-2}	2.51×10^{-8}	$1.01\times10^{+6}$	β 98	MS LSC +	
^{171}Yb	stable	6.78×10^{-1}*	0	2.26×10^{-5}	0		MS +	
^{172}Yb	stable	4.46×10^{-1}*	0	1.49×10^{-5}	0		MS +	
^{172}Hf	1.87 y	2.82×10^{-1}*	$1.16\times10^{+1}$	4.22×10^{-6}	$1.74\times10^{+8}$	γ 126 *11*	MS + IGS + GS +	
^{172}Lu	6.7 d	2.77×10^{-15}	$1.16\times10^{+1}$	4.14×10^{-8}	$1.74\times10^{+8}$	γ 901 *29* γ 1094 *64*	IGS + GS +	
^{173}Yb	stable	5.26×10^{-1}*	0	1.75×10^{-5}	0		MS +	
^{173}Lu	1.37 y	3.29×10^{-1}*	$1.84\times10^{+1}$	3.68×10^{-6}	$2.05\times10^{+8}$	γ 272 *13*	IGS + GS +	
^{174}Yb	stable	4.36×10^{-2}*	0	1.45×10^{-6}	0		MS +	
^{174m}Lu	142.0 d	5.28×10^{-2}*	$1.03\times10^{+1}$	3.74×10^{-8}	$7.31\times10^{+6}$	X *65*	LEP -	+

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Comments (see end of table)
^{174}Lu	3.3 y	5.28×10^{-2}*	$1.22\times10^{+0}$	1.12×10^{-6}	$2.58\times10^{+7}$	γ 1242 *7*	IGS GS + LEP -	+
^{174}Hf	2.0×10^{15} y	7.09×10^{-1}*	2.70×10^{-14}	2.36×10^{-5}	8.98×10^{-7}	α 2500	MS + AS -	
^{175}Lu	stable	$1.15\times10^{+0}$*	0	3.83×10^{-5}	0		MS +	
^{175}Hf	70.0 d	1.77×10^{-2}*	$6.98\times10^{+0}$	2.39×10^{-10}	$9.41\times10^{+4}$	γ 343 *87*	IGS GS +	
^{176}Yb	stable	9.37×10^{-4}*	0	3.12×10^{-8}	0		MS	
^{176}Lu	3.6×10^{10} y	6.61×10^{-2}*	1.38×10^{-10}	2.20×10^{-6}	4.60×10^{-3}	β 565	MS + LSC -	
^{176}Hf	stable	$1.26\times10^{+0}$*	0	4.20×10^{-5}	0		MS +	
^{177}Hf	stable	$1.44\times10^{+0}$*	0	4.80×10^{-5}	0		MS +	
^{178}Hf	stable	6.65×10^{-1}*	0	2.22×10^{-5}	0		MS +	
^{178}W	21.5 d	8.99×10^{-6}*	1.14×10^{-2}	2.69×10^{-21}	3.39×10^{-6}	X *25*	LEP -	
^{178}Ta	9.31 m	2.70×10^{-21}	1.14×10^{-2}	8.09×10^{-25}	3.39×10^{-6}	X *85*	LEP -	
^{179}Hf	stable	4.46×10^{-1}*	0	1.49×10^{-5}	0		MS +	

Nuclide	Half-life	Amount in the target 1/2/95 [g]	Activity in the target 1/2/95 [TBq]	Mean content 1/4/97 [g/g target]	Mean specific activity 1/4/97 [Bq/g target]	Radiations (explanations see p. 21)	Analytical techniques (explanations see p. 22)	Com-ments (see end of table)
^{179}Ta	1.8 y	$6.42\times10^{-2*}$	$2.64\times10^{+0}$	9.31×10^{-7}	$3.82\times10^{+7}$	X *47*	MS +	
^{180}Hf	stable	not calc.	not calc.	not calc.	not calc.		MS ?	
^{180}Ta	1.2×10^{15} y	$2.59\times10^{-2*}$	1.59×10^{-15}	8.63×10^{-7}	5.29×10^{-8}		MS +	
^{180}W	stable	$6.76\times10^{-2*}$	0	2.25×10^{-6}	0		MS +	
^{181}Hf	42.4 d	not calc.	not calc.	not calc.	not calc.	γ 345 *15* γ 482 *81*	GS ?	
^{181}Ta	stable	$2.50\times10^{-2*}$	0	8.33×10^{-7}	0		-	
^{181}W	121.2 d	$1.66\times10^{-3*}$	3.66×10^{-1}	6.07×10^{-10}	$1.34\times10^{+5}$	X *66*	LSC	
^{182}Hf	9.0×10^{6} y	not calc.	not calc.	not calc.	not calc.		MS ?	
^{182}Ta	114.43 d	not calc.	not calc.	not calc.	not calc.	γ 1121 *35* γ 1221 *27*	GS ?	

B.3 Comments on Table 1

^{40}K

The activity and correspondingly the γ-line of ^{40}K is too weak to be found beside the Compton and bremsstrahlung radiation of the other activities. After chemical separation of K it may be found, but even then the detection limit is comparatively high because ^{40}K is part of the natural background. It may possibly be measured with the low-level γ-ray spectrometer at ZCH. See also comment on ^{40}Ar.

^{40}Ar

As a gas, argon is lost when samples are dissolved in an acid. Therefore, this nuclide cannot be measured after separation of Ta. For direct determination by solid-state mass spectrometry the activities of appropriate samples are presumably too high and the sum of the weights of nuclides with M=40 is presumably too low. Additionally, small amounts of ^{40}Ar may be in the sample chamber and interfere with the determination of the spallation product.

^{40}Ca

See comment on ^{40}Ar.

^{41}K

The sum of the weight of nuclides with M=41 is presumably too low for the determination by ICP-MS, even after separation of Ta.

^{41}Ca

Even after separation of Ca from the target the radiation is too weak to be detected by LSC beside that of ^{45}Ca.

^{42}Ar and ^{42}K

When the sample is dissolved and Ta is separated, Ar will escape as a gas, but its daughter, ^{42}K, remains in the solution and can be measured by γ-ray spectrometry, if the measurement is done within one day of dissolution. K may have to be separated from other elements before measurement.

^{42}Ca

For the determination of the sum of weights of the nuclides with M=42 the same holds as is described for ^{40}Ar, because ^{42}Ar will also escape as a gas, and the total weight is too low to be determined by ICP-MS.

^{45}Ca

This nuclide can be measured by LSC provided that a radiochemical separation procedure is developed at ZCH.

^{46}Sc

It is doubtful whether this nuclide can be found in the γ-spectrum of the unseparated sample, but it can certainly be measured after separation of Sc.

^{49}V

Due to its decay properties, this nuclide is difficult to measure by LSC, and an effective separation procedure is required to remove all other radionuclides.

^{53}Mn

The nuclide emits no γ-rays and the radiation emitted with its electron capture process cannot be measured in the presence of ^{54}Mn. NAA of ^{53}Mn would yield ^{54}Mn, which is already present in the sample. Therefore only ICP-MS offers a chance to measure this nuclide. An effective technique, but not available at KFA, is accelerator mass spectrometry.

^{55}Fe

This nuclide can be measured by LSC provided that a radiochemical separation procedure is developed at ZCH.

^{59}Ni

Cannot be chemically separated from ^{63}Ni and therefore cannot be measured by LSC.

^{60}Fe

Cannot be chemically separated from ^{55}Fe and therefore cannot be measured by LSC. The decay properties are not well known.

^{63}Ni

This nuclide can be measured by LSC provided that a radiochemical separation procedure is developed at ZCH. The contribution of ^{59}Ni to the counting rate is negligible if the ratio of the calculated spallation yields is correct.

^{68}Ge and ^{68}Ga

This nuclide can be measured by LSC provided that a radiochemical separation procedure is developed at ZCH. The measurement by γ-spectrometry of its daughter ^{68}Ga is preferable, although it emits only a weak line at 1077 keV and may require chemical separation. An interference by ^{86}Rb, which emits a line with nearly the same energy, is excluded because this nuclide has decayed at the time of measurement.

^{73}As

The nuclide only emits a γ-line at 53 keV. In a "thick" tantalum sample γ-ray self-absorption may be a source of error and the nuclide should be separated before counting.

^{74}As

Due to the short half-life the activity has become too low for measurement by γ-ray spectrometry or other counting techniques.

^{73}Se

This short-lived nuclide has no long-lived predecessor. It is not clear why it is listed among the spallation products in the RAL tables. Its calculated weight is surely too high.

^{78}Kr

Will escape during dissolution of the sample and therefore cannot be measured by the analytical techniques considered here. Because this nuclide contributes an essential part to the sum of the weights of this mass chain, the determination of this weight sum by ICP-MS is not possible in the dissolved sample.

^{79}Se

Cannot be chemically separated from ^{75}Se and therefore cannot be measured by LSC.

^{81}Kr

See comment on ^{78}Kr.

^{82}Sr and ^{82}Rb

Due to the short half-life the activity has become too low for measurement of ^{82}Sr by LSC. For the same reason the daughter, ^{82}Rb, cannot be measured by γ-ray spectrometry either.

^{83}Kr

See comment on ^{78}Kr.

^{84}Kr

See comment on ^{78}Kr.

^{84}Rb

Due to the short half-life the activity has become too low for measurement by LSC.

^{85}Kr

Will escape during dissolution of the sample and therefore LSC or γ-ray spectrometry after chemical separation is not possible. For direct γ-ray spectrometry its γ-line is too weak and is superimposed by that of ^{85}Sr.

^{86}Kr

See comment on ^{78}Kr, but here the contribution of Kr to the sum weight of the mass chain is small and the total sum may be determined with only a small error.

^{86}Rb

Due to the short half-life the activity has become too low for measurement by γ-ray spectrometry or other counting techniques.

^{88}Zr

If the ratios of the weights of the spallation products belonging to zirconium are correctly calculated, then the activities of ^{93}Zr and ^{95}Zr are much lower than that of ^{88}Zr, so that after chemical separation of Zr the nuclide can be measured by γ-ray spectrometry.

^{89}Sr

Cannot be chemically separated from ^{90}Sr and therefore cannot be measured by LSC.

^{90}Sr/^{90}Y

Sr has to be chemically separated and then it can be measured by LSC. A special counting technique, based on the build-up of ^{90}Y and counting the Cerenkov radiation in an LSC, has been developed for the determination of ^{90}Sr in fission products [8] and can possibly be adapted to the analysis of the Ta target.

^{91}Y

Cannot be chemically separated from ^{88}Y and therefore cannot be measured by LSC. Its γ-line at 1205 keV is too weak to allow a sensitive determination.

^{91}Nb

Of the spallation products belonging to the element Nb, the activity of ^{91}Nb is by far the highest, so that after chemical separation the LSC counting rate with a negligible error can be ascribed to this nuclide. What is known about the spallation yield of the metastable ^{91m}Nb ($T_{1/2}$=62 d)?

^{92}Nb

The activity is very weak so that it cannot be found in the γ-spectrum of the original sample. After separation of Nb it can possibly be measured by γ-ray spectrometry.

^{93}Zr

Cannot be chemically separated from ^{88}Zr and ^{95}Zr and therefore cannot be measured by LSC.

^{93m}Nb

Is generated as a daughter of ^{93}Zr and ^{93}Mo and - presumably (to what extent?) - as a primary spallation product. Due to its long half-life it is not in equilibrium with its predecessors. It cannot be chemically separated from ^{94}Nb and therefore cannot be measured by LSC.

^{93}Mo

After chemical separation of Mo LSC is possible because no other Mo isotopes are radioactive.

^{95}Zr/^{95m}Nb/^{95}Nb

From this decay chain, which is in transient equilibrium after the long decay time, the main γ-lines can possibly be seen in the spectrum of the untreated sample. If not, ^{95}Zr has to be separated.

^{97}Tc, ^{98}Tc, ^{99}Tc

After separation of Tc, ^{98}Tc can be determined by γ-ray spectrometry. ^{99}Tc can be measured by LSC. ^{98}Tc will contribute only a small amount to the counting rate in the LSC and, since its activity is known, its contribution can be subtracted. ^{97}Tc also contributes a slight amount to the LSC counting rate but - because of the low energy of its radiation - this contribution can be suppressed by appropriate setting of the lower discriminator.

^{99}Rh

Due to the short half-life the activity has become too low for measurement by γ-ray spectrometry or other counting techniques.

^{102m}Rh and ^{102}Rh

Presumably both the metastable and the ground state of this nuclide are generated during the spallation process, but their yields cannot be calculated separately. The nuclides can be distinguished by their γ-spectra.

^{105}Ag

Due to the short half-life the activity has become too low for measurement by γ-ray spectrometry or other counting techniques.

^{109}In

This short-lived nuclide has no long-lived predecessor. It is not clear why it is listed among the spallation products in the RAL tables. Its calculated activity is surely too high.

^{115m}Cd

Due to the short half-life the activity has become too low for measurement by γ-ray spectrometry or other counting techniques.

^{119m}Sn

Because it cannot be chemically separated from ^{123}Sn, it cannot be measured by LSC. It may possibly be determined via its X-rays measured by low-energy photon γ-spectrometry.

^{123}Sn

It cannot be chemically separated from ^{119m}Sn, but the X-rays and Auger electrons of this nuclide may be suppressed in the β-spectrum of ^{123}Sn by appropriate setting of the low energy discriminator or by appropriate β-spectrum evaluation techniques.

^{125}I

It depends on the dissolution method whether I_2 escapes from the sample as a gas and is lost, but the expulsion may also be used as a separation method for I_2. Its activity is much higher than that of ^{129}I so that it might be measured by LSC. Low-energy photon γ-spectrometry may also be useful.

^{127}Xe

Will escape during dissolution of the sample and therefore γ-ray spectrometry after chemical separation is not possible. Its activity is too low for direct γ-ray spectrometry.

^{128}Xe

Will escape during dissolution of the sample and therefore cannot be measured by the analytical techniques considered here.

^{129m}Te and ^{129}Te

Due to the short half-life the activities have become too low for measurement by γ-ray spectrometry or other counting techniques.

^{129}I

See comment on ^{125}I. Because of the much stronger activity of this nuclide, ^{129}I cannot be measured by LSC. Neutron activation, which yields ^{130}I, a nuclide whose γ-rays are easily measurable, may be applied, but is circumstantial.

^{129}Xe

See comment on ^{128}Xe.

^{130}Xe

See comment on ^{128}Xe. Because this nuclide contributes an essential part to the sum of the weights of this mass chain, the determination of this weight sum by ICP-MS is not possible in the dissolved sample.

^{131}Ba and ^{131}Cs

Due to the short half-lives of this pair of nuclides the activities are too low for measurement by γ-ray spectrometry or other counting techniques.

^{131}Xe, ^{132}Xe, ^{134}Xe and ^{136}Xe

See comment on ^{128}Xe.

^{145}Sm and ^{145}Pm

In this decay chain Sm is the mother and Pm the daughter, both decaying by electron capture. LSC might be applicable and low-energy photon spectrometry of the X-rays may also be a good choice.

^{147}Eu

Due to the short half-life the activity has become too low for measurement by γ-ray spectrometry or other counting techniques.

^{148}Eu

This short-lived nuclide has no long-lived predecessor. It is not clear why it is listed among the spallation products in the RAL tables. Its calculated weight is surely too high.

^{156}Eu

See comment on ^{147}Eu.

^{163}Ho

Decay properties, esp. X-ray intensities, are not well known

^{169}Yb

Due to the short half-life the activity has become too low for measurement by γ-ray spectrometry or other counting techniques.

^{174m}Lu and ^{174}Lu

These two nuclides are difficult to distinguish by their X-rays with low-energy photon spectrometry, because the lines strongly overlap. The longer-lived daughter nuclide can possibly be determined via the weak γ-line at 1242 keV.

^{178}W and ^{178}Ta

Due to the short half-lives of this pair of nuclides the activities have become too low for measurement by low-energy photon γ-spectrometry or other counting techniques.

^{180}Ta and ^{181}Ta

These two nuclides are the material the target is made of. Therefore the amount of ^{181}Ta should be 3.0×10^{7} g instead of the number given in the RAL table, 2.5×10^{-2} g. The amount of ^{180}Ta possibly does not correspond to the natural isotopic abundance (0.0123 %), because it may be changed by the spallation process.

^{182}Ta

The activity of this nuclide is not calculated by the RAL program. But it has to be assumed that a small amount of neutrons were moderated to low energies and have generated it by (n,γ)-reactions from the target material during its use in ISIS. It is likely that at the prospective time of measurement, it is still among the most active radionuclides in the target.

Appendix C. Table 3 - Sum contents of groups of isobaric nuclides

Nuclide	Half-life	Content [g/g]
^{35}Cl	stable	7.67×10^{-10}
Sum for M = 35		**7.67×10^{-10}**
^{40}K	1.28×10^{09} y	8.77×10^{-10}
^{40}Ar	stable	1.75×10^{-09}
^{40}Ca	stable	8.77×10^{-10}
Sum for M = 40		**3.50×10^{-09}**
^{41}K	stable	1.80×10^{-09}
^{41}Ca	1.03×10^{05} y	1.80×10^{-09}
Sum for M = 41		**3.60×10^{-09}**
^{42}Ar	32.9 y	8.38×10^{-10}
^{42}K	12.38 h	3.60×10^{-14}
^{42}Ca	stable	3.73×10^{-09}
Sum for M = 42		**4.57×10^{-09}**
^{43}Ca	stable	3.73×10^{-09}
Sum for M = 43		**3.73×10^{-09}**
^{44}Ca	stable	3.87×10^{-09}
Sum for M = 44		**3.87×10^{-09}**
^{45}Ca	162.7 d	7.47×10^{-12}
^{45}Sc	stable	4.73×10^{-09}
Sum for M = 45		**4.74×10^{-09}**

Nuclide	Half-life	Content [g/g]
^{46}Ca	stable	2.02×10^{-09}
^{46}Sc	83.81 d	3.98×10^{-14}
^{46}Ti	stable	3.00×10^{-09}
Sum for M = 46		**5.02×10^{-09}**
^{47}Ti	stable	8.40×10^{-09}
Sum for M = 47		**8.40×10^{-09}**
^{48}Ti	stable	3.11×10^{-09}
Sum for M = 48		**3.11×10^{-09}**
^{49}Ti	stable	9.13×10^{-09}
^{49}V	337 d	2.69×10^{-10}
Sum for M = 49		**9.40×10^{-09}**
^{50}Ti	stable	5.43×10^{-09}
^{50}V	stable	4.33×10^{-09}
Sum for M = 50		**9.76×10^{-09}**
^{51}V	stable	1.31×10^{-08}
^{51}Cr	27.7 d	4.78×10^{-21}
Sum for M = 51		**1.31×10^{-08}**
^{52}Cr	stable	1.60×10^{-08}
Sum for M = 52		**1.60×10^{-08}**

Nuclide	Half-life	Content [g/g]
^{53}Cr	stable	7.87×10^{-09}
^{53}Mn	3.7×10^{06} y	5.53×10^{-09}
Sum for M = 53		**1.34×10^{-08}**
^{54}Cr	stable	1.20×10^{-08}
^{54}Mn	312.2 d	5.71×10^{-10}
^{54}Fe	stable	1.18×10^{-09}
Sum for M = 54		**1.38×10^{-08}**
^{55}Mn	stable	1.17×10^{-08}
^{55}Fe	2.73 y	1.62×10^{-09}
Sum for M = 55		**1.33×10^{-08}**
^{56}Fe	stable	1.93×10^{-08}
^{56}Co	77.3 d	4.74×10^{-14}
Sum for M = 56		**1.93×10^{-08}**
^{57}Fe	stable	1.98×10^{-08}
^{57}Co	271.8 d	3.36×10^{-10}
Sum for M = 57		**2.01×10^{-08}**
^{58}Fe	stable	1.63×10^{-08}
^{58}Co	70.88 d	8.66×10^{-14}
^{58}Ni	stable	3.77×10^{-09}
Sum for M = 58		**2.01×10^{-08}**
^{59}Fe	44.51 d	3.93×10^{-17}
^{59}Co	stable	2.04×10^{-08}
^{59}Ni	76000 y	3.83×10^{-09}
Sum for M = 59		**2.42×10^{-08}**

Nuclide	Half-life	Content [g/g]
^{60}Fe	1.5×10^{06} y	3.87×10^{-09}
^{60}Co	5.271 y	2.94×10^{-09}
^{60}Ni	stable	2.83×10^{-08}
Sum for M = 60		**3.51×10^{-08}**
^{61}Ni	stable	3.15×10^{-08}
Sum for M = 61		**3.15×10^{-08}**
^{62}Ni	stable	5.97×10^{-08}
Sum for M = 62		**5.97×10^{-08}**
^{63}Ni	100 y	5.29×10^{-09}
^{63}Cu	stable	4.20×10^{-08}
Sum for M = 63		**4.73×10^{-08}**
^{64}Ni	stable	1.71×10^{-08}
^{64}Zn	stable	4.80×10^{-08}
Sum for M = 64		**6.51×10^{-08}**
^{65}Cu	stable	4.13×10^{-08}
^{65}Zn	243.8 d	8.28×10^{-10}
Sum for M = 65		**4.21×10^{-08}**
^{66}Zn	stable	7.53×10^{-08}
Sum for M = 66		**7.53×10^{-08}**
^{67}Zn	stable	9.43×10^{-08}
Sum for M = 67		**9.43×10^{-08}**

Nuclide	Half-life	Content [g/g]
^{68}Zn	stable	6.30×10^{-08}
^{68}Ge	270.8 d	6.81×10^{-10}
^{68}Ga	1.13 h	1.18×10^{-13}
Sum for M = 68		**6.37×10^{-08}**
^{69}Ga	stable	8.80×10^{-08}
Sum for M = 69		**8.80×10^{-08}**
^{70}Zn	stable	3.09×10^{-09}
^{70}Ge	stable	1.45×10^{-07}
Sum for M = 70		**1.48×10^{-07}**
^{71}Ga	stable	1.01×10^{-07}
Sum for M = 71		**1.01×10^{-07}**
^{72}Ge	stable	1.40×10^{-07}
Sum for M = 72		**1.40×10^{-07}**
^{73}Ge	stable	6.33×10^{-09}
^{73}As	80.3 d	4.08×10^{-12}
^{73}Se	7.1 h	0
Sum for M = 73		**6.33×10^{-09}**
^{74}Ge	stable	1.11×10^{-08}
^{74}As	17.78 d	0
^{74}Se	stable	1.28×10^{-07}
Sum for M = 74		**1.39×10^{-07}**
^{75}As	stable	1.18×10^{-07}
^{75}Se	119.78 d	6.45×10^{-11}
Sum for M = 75		**1.18×10^{-07}**

Nuclide	Half-life	Content [g/g]
^{76}Ge	stable	1.67×10^{-09}
^{76}Se	stable	2.08×10^{-07}
Sum for M = 76		**2.10×10^{-07}**
^{77}Se	stable	2.34×10^{-07}
Sum for M = 77		**2.34×10^{-07}**
^{78}Se	stable	6.97×10^{-08}
^{78}Kr	stable	2.03×10^{-07}
Sum for M = 78		**2.73×10^{-07}**
^{79}Se	6.5×10^{04} y	1.73×10^{-09}
^{79}Br	stable	2.19×10^{-07}
Sum for M = 79		**2.21×10^{-07}**
^{80}Se	stable	7.20×10^{-09}
^{80}Kr	stable	3.13×10^{-07}
Sum for M = 80		**3.20×10^{-07}**
^{81}Br	stable	1.02×10^{-08}
^{81}Kr	2.15×10^{05} y	2.69×10^{-07}
Sum for M = 81		**2.79×10^{-07}**
^{82}Kr	stable	3.93×10^{-07}
^{82}Sr	25.36 d	1.21×10^{-20}
^{82}Rb	1.27 m	4.21×10^{-25}
Sum for M = 82		**3.93×10^{-07}**
^{83}Kr	stable	3.83×10^{-07}
^{83}Rb	86.2 d	1.92×10^{-11}
Sum for M = 83		**3.83×10^{-07}**

Nuclide	Half-life	Content [g/g]
^{84}Kr	stable	6.17×10^{-08}
^{84}Rb	32.9 d	2.54×10^{-18}
^{84}Sr	stable	4.30×10^{-07}
Sum for M = 84		**4.92×10^{-07}**
^{85}Kr	10.73 y	2.30×10^{-09}
^{85}Rb	stable	5.00×10^{-07}
^{85}Sr	64.84 d	1.33×10^{-12}
Sum for M = 85		**5.02×10^{-07}**
^{86}Kr	stable	1.88×10^{-09}
^{86}Rb	18.65 d	6.66×10^{-26}
^{86}Sr	stable	8.03×10^{-07}
Sum for M = 86		**8.05×10^{-07}**
^{87}Rb	stable	1.47×10^{-08}
^{87}Sr	stable	9.77×10^{-07}
Sum for M = 87		**9.92×10^{-07}**
^{88}Sr	stable	1.57×10^{-06}
^{88}Y	106.6 d	7.77×10^{-10}
^{88}Zr	83.4 d	4.20×10^{-11}
Sum for M = 88		**1.57×10^{-06}**
^{89}Sr	50.52 d	5.65×10^{-15}
^{89}Y	stable	2.29×10^{-06}
Sum for M = 89		**2.29×10^{-06}**
^{90}Sr	29.1 y	1.19×10^{-08}
^{90}Y	2.67 d	2.99×10^{-12}
^{90}Zr	stable	1.49×10^{-06}
Sum for M = 90		**1.50×10^{-06}**

Nuclide	Half-life	Content [g/g]
^{91}Y	58.5 d	1.68×10^{-13}
^{91}Zr	stable	7.00×10^{-07}
^{91}Nb	680.0 y	5.12×10^{-08}
Sum for M = 91		**7.51×10^{-07}**
^{92}Zr	stable	5.33×10^{-07}
^{92}Nb	3.6×10^{07} y	2.78×10^{-08}
^{92}Mo	stable	7.97×10^{-09}
Sum for M = 92		**5.69×10^{-07}**
^{93}Zr	1.5×10^{06} y	3.21×10^{-07}
^{93m}Nb	13.6 y	4.77×10^{-13}
^{93}Nb	stable	2.23×10^{-08}
^{93}Mo	3500 y	1.38×10^{-08}
Sum for M = 93		**3.57×10^{-07}**
^{94}Zr	stable	2.45×10^{-07}
^{94}Nb	20000 y	9.80×10^{-09}
^{94}Mo	stable	1.38×10^{-08}
Sum for M = 94		**2.69×10^{-07}**
^{95}Zr	64.02 d	1.35×10^{-13}
^{95m}Nb	3.61 d	7.22×10^{-17}
^{95}Nb	34.97 d	1.62×10^{-13}
^{95}Mo	stable	7.47×10^{-08}
Sum for M = 95		**7.47×10^{-08}**
^{96}Zr	stable	2.10×10^{-08}
^{96}Mo	stable	8.40×10^{-09}
^{96}Ru	stable	6.20×10^{-09}
Sum for M = 96		**3.56×10^{-08}**

Nuclide	Half-life	Content [g/g]
^{97}Mo	stable	8.40×10^{-09}
^{97}Tc	2.6×10^{06} y	1.09×10^{-08}
Sum for M = 97		**1.93×10^{-08}**
^{98}Mo	stable	8.60×10^{-09}
^{98}Tc	4.2×10^{06} y	6.33×10^{-09}
^{98}Ru	stable	8.50×10^{-09}
Sum for M = 98		**2.34×10^{-08}**
^{99}Tc	2.13×10^{05} y	6.53×10^{-09}
^{99}Rh	16.0 d	0
^{99}Ru	stable	1.71×10^{-08}
Sum for M = 99		**2.36×10^{-08}**
^{100}Mo	stable	4.37×10^{-09}
^{100}Ru	stable	6.63×10^{-09}
Sum for M = 100		**1.10×10^{-08}**
^{101}Ru	stable	6.00×10^{-09}
^{101}Rh	3.3 y	1.82×10^{-09}
Sum for M = 101		**7.82×10^{-09}**
^{102}Ru	stable	9.27×10^{-09}
^{102m}Rh	207.0 d	2.87×10^{-10}
^{102}Rh	2.9 y	2.41×10^{-09}
^{102}Pd	stable	8.83×10^{-09}
Sum for M = 102		**2.08×10^{-08}**
^{103}Rh	stable	1.57×10^{-08}
Sum for M = 103		**1.57×10^{-08}**

Nuclide	Half-life	Content [g/g]
^{104}Ru	stable	2.28×10^{-09}
^{104}Pd	stable	9.10×10^{-09}
Sum for M = 104		**1.14×10^{-08}**
^{105}Pd	stable	2.30×10^{-08}
^{105}Ag	41.3 d	5.73×10^{-17}
Sum for M = 105		**2.30×10^{-08}**
^{106}Pd	stable	6.97×10^{-09}
^{106}Cd	stable	9.17×10^{-09}
Sum for M = 106		**1.61×10^{-08}**
^{107}Pd	6.5×10^{06} y	9.27×10^{-09}
^{107}Ag	stable	1.17×10^{-08}
Sum for M = 107		**2.10×10^{-08}**
^{108}Pd	stable	2.53×10^{-09}
^{108}Cd	stable	1.39×10^{-08}
Sum for M = 108		**1.64×10^{-08}**
^{109}Ag	stable	2.39×10^{-09}
^{109}Cd	462 d	1.06×10^{-09}
^{109}In	4.2 h	0
Sum for M = 109		**3.45×10^{-09}**
^{110}Pd	stable	5.70×10^{-12}
^{110m}Ag	249.8 d	5.38×10^{-11}
^{110}Cd	stable	1.63×10^{-08}
Sum for M = 110		**1.64×10^{-08}**
^{111}Cd	stable	2.25×10^{-08}
Sum for M = 111		**2.25×10^{-08}**

Nuclide	Half-life	Content [g/g]
^{112}Cd	stable	2.46×10^{-08}
^{112}Sn	stable	1.99×10^{-08}
Sum for M = 112		**4.45×10^{-08}**
^{113}Cd	stable	2.48×10^{-08}
^{113}In	stable	1.65×10^{-08}
^{113}Sn	115.1 d	2.40×10^{-12}
Sum for M = 113		**4.13×10^{-08}**
^{114}Sn	stable	2.76×10^{-08}
Sum for M = 114		**2.76×10^{-08}**
^{115m}Cd	44.6 d	3.35×10^{-18}
^{115}In	stable	9.93×10^{-09}
^{115}Sn	stable	1.76×10^{-08}
Sum for M = 115		**2.75×10^{-08}**
^{116}Cd	stable	2.54×10^{-09}
^{116}Sn	stable	2.81×10^{-08}
Sum for M = 116		**3.06×10^{-08}**
^{117}Sn	stable	2.80×10^{-08}
Sum for M = 117		**2.80×10^{-08}**
^{118}Sn	stable	3.28×10^{-08}
Sum for M = 118		**3.28×10^{-08}**
^{119}Sn	stable	3.67×10^{-08}
^{119m}Sn	293 d	1.67×10^{-12}
Sum for M = 119		**3.67×10^{-08}**

Nuclide	Half-life	Content [g/g]
^{120}Sn	stable	7.77×10^{-09}
^{120}Te	stable	2.66×10^{-08}
Sum for M = 120		**3.44×10^{-08}**
^{121}Sn	stable	3.70×10^{-08}
^{121}Sb	stable	2.97×10^{-08}
^{121}Te	154 d	1.62×10^{-16}
Sum for M = 121		**6.67×10^{-08}**
^{122}Sn	stable	0
^{122}Te	stable	3.07×10^{-08}
Sum for M = 122		**3.07×10^{-08}**
^{123}Sn	129.2 d	2.76×10^{-12}
^{123}Sb	stable	2.51×10^{-09}
^{123}Te	1.3×10^{13} y	3.50×10^{-08}
Sum for M = 123		**3.75×10^{-08}**
^{124}Sb	60.2 d	0
^{124}Te	stable	1.12×10^{-08}
^{124}Xe	stable	4.30×10^{-08}
Sum for M = 124		**5.42×10^{-08}**
^{125}Te	stable	6.57×10^{-08}
^{125}I	60.1 d	7.41×10^{-14}
Sum for M = 125		**6.57×10^{-08}**
^{126}Te	stable	1.53×10^{-09}
^{126}Xe	stable	8.33×10^{-08}
Sum for M = 126		**8.48×10^{-08}**

Nuclide	Half-life	Content [g/g]
^{127}I	stable	1.16×10^{-07}
^{127}Xe	36.4 d	4.56×10^{-17}
Sum for M = 127		**1.16×10^{-07}**
^{128}Xe	stable	1.42×10^{-07}
Sum for M = 128		**1.42×10^{-07}**
^{129m}Te	33.6 d	1.15×10^{-20}
^{129}Te	1.16 h	1.65×10^{-23}
^{129}I	1.57×10^{07} y	5.67×10^{-09}
^{129}Xe	stable	1.24×10^{-07}
Sum for M = 129		**1.30×10^{-07}**
^{130}Xe	stable	8.27×10^{-08}
^{130}Ba	stable	1.47×10^{-07}
Sum for M = 130		**2.30×10^{-07}**
^{131}Ba	11.7 d	0
^{131}Cs	9.69 d	0
^{131}Xe	stable	2.37×10^{-07}
Sum for M = 131		**2.37×10^{-07}**
^{132}Xe	stable	0
^{132}Ba	stable	2.82×10^{-07}
Sum for M = 132		**2.82×10^{-07}**
^{133}Cs	stable	3.50×10^{-08}
^{133}Ba	10.53 y	1.94×10^{-07}
Sum for M = 133		**2.29×10^{-07}**

Nuclide	Half-life	Content [g/g]
^{134}Xe	stable	0
^{134}Cs	2.065 y	0
^{134}Ba	stable	3.67×10^{-07}
Sum for M = 134		**3.67×10^{-07}**
^{135}Ba	stable	3.93×10^{-07}
Sum for M = 135		**3.93×10^{-07}**
^{136}Xe	stable	0
^{136}Ba	stable	1.18×10^{-08}
^{136}Ce	stable	5.43×10^{-07}
Sum for M = 136		**5.55×10^{-07}**
^{137}Cs	30.17 y	0
^{137}Ba	stable	0
Sum for M = 137		**$0.00\times10^{+00}$**
^{138}Ba	stable	0
^{138}La	stable	0
^{138}Ce	stable	8.40×10^{-07}
Sum for M = 138		**8.40×10^{-07}**
^{139}La	stable	8.80×10^{-07}
^{139}Ce	137.6 d	1.43×10^{-09}
Sum for M = 139		**8.81×10^{-07}**
^{140}Ce	stable	1.09×10^{-06}
Sum for M = 140		**1.09×10^{-06}**
^{141}Ce	32.5 d	0
^{141}Pr	stable	1.17×10^{-06}
Sum for M = 141		**1.17×10^{-06}**

Nuclide	Half-life	Content [g/g]
^{142}Ce	stable	0
^{142}Nd	stable	1.44×10^{-06}
Sum for M = 142		**1.44×10^{-06}**
^{143}Nd	stable	1.16×10^{-06}
^{143}Pm	265.0 d	3.90×10^{-08}
Sum for M = 143		**1.20×10^{-06}**
^{144}Ce	284.6 d	0
^{144}Nd	stable	7.30×10^{-08}
^{144}Pm	363.0 d	5.89×10^{-09}
^{144}Sm	stable	1.67×10^{-06}
Sum for M = 144		**1.75×10^{-06}**
^{145}Sm	340 d	1.00×10^{-07}
^{145}Pm	17.7 y	1.17×10^{-06}
^{145}Nd	stable	9.50×10^{-08}
Sum for M = 145		**1.36×10^{-06}**
^{146}Nd	stable	2.74×10^{-09}
^{146}Pm	5.53 y	1.06×10^{-08}
^{146}Sm	1.03×10^{08} y	2.03×10^{-06}
^{146}Gd	48.3 d	7.01×10^{-14}
^{146}Eu	4.57 d	6.64×10^{-15}
Sum for M = 146		**2.04×10^{-06}**
^{147}Pm	2.6234 y	6.07×10^{-09}
^{147}Sm	1.06×10^{11} y	2.25×10^{-06}
^{147}Eu	24.4 d	1.95×10^{-21}
Sum for M = 147		**2.26×10^{-06}**

Nuclide	Half-life	Content [g/g]
^{148}Nd	stable	0
^{148}Sm	7.0×10^{14} y	3.05×10^{-07}
^{148}Eu	54.5 d	8.05×10^{-14}
^{148}Gd	75 y	2.16×10^{-06}
^{148}Tb	1.00 h	0
Sum for M = 148		**2.46×10^{-06}**
^{149}Sm	stable	2.48×10^{-06}
^{149}Eu	93.1 d	2.67×10^{-10}
Sum for M = 149		**2.48×10^{-06}**
^{150}Nd	stable	0
^{150}Sm	stable	6.27×10^{-09}
^{150m}Eu	36.0 y	6.33×10^{-08}
^{150}Gd	1.8×10^{06} y	2.50×10^{-06}
Sum for M = 150		**2.57×10^{-06}**
^{151}Sm	90 y	3.20×10^{-09}
^{151}Eu	stable	2.79×10^{-06}
^{151}Gd	120 d	1.89×10^{-09}
Sum for M = 151		**2.80×10^{-06}**
^{152}Sm	stable	1.07×10^{-09}
^{152}Eu	13.48 y	1.04×10^{-08}
^{152}Gd	1.1×10^{14} y	3.70×10^{-06}
Sum for M = 152		**3.71×10^{-06}**
^{153}Eu	stable	3.04×10^{-06}
^{153}Gd	241.6 d	7.49×10^{-08}
Sum for M = 153		**3.11×10^{-06}**

Nuclide	Half-life	Content [g/g]
^{154}Sm	stable	0
^{154}Eu	8.59 y	2.37×10^{-09}
^{154}Gd	stable	3.53×10^{-07}
^{154}Dy	3.0×10^{06} y	4.07×10^{-06}
Sum for M = 154		**4.43×10^{-06}**
^{155}Eu	4.71 y	0
^{155}Gd	stable	4.67×10^{-06}
Sum for M = 155		**4.67×10^{-06}**
^{156}Eu	15.2 d	0
^{156}Gd	stable	7.80×10^{-08}
^{156}Dy	stable	4.70×10^{-06}
Sum for M = 156		**4.78×10^{-06}**
^{157}Gd	stable	5.50×10^{-08}
^{157}Tb	150 y	5.12×10^{-06}
Sum for M = 157		**5.18×10^{-06}**
^{158}Gd	stable	6.00×10^{-11}
^{158}Tb	150 y	6.80×10^{-09}
^{158}Dy	stable	5.97×10^{-06}
Sum for M = 158		**5.98×10^{-06}**
^{159}Tb	stable	6.30×10^{-06}
^{159}Dy	144.4 d	1.35×10^{-08}
Sum for M = 159		**6.31×10^{-06}**
^{160}Gd	stable	0
^{160}Tb	72.3 d	0
^{160}Dy	stable	7.43×10^{-06}
Sum for M = 160		**7.43×10^{-06}**

Nuclide	Half-life	Content [g/g]
^{161}Dy	stable	6.50×10^{-06}
Sum for M = 161		**6.50×10^{-06}**
^{162}Dy	stable	1.08×10^{-07}
^{162}Er	stable	9.07×10^{-06}
Sum for M = 162		**9.18×10^{-06}**
^{163}Dy	stable	2.71×10^{-07}
^{163}Ho	33.0 y	5.19×10^{-06}
Sum for M = 163		**5.46×10^{-06}**
^{164}Dy	stable	1.49×10^{-08}
^{164}Er	stable	1.03×10^{-05}
Sum for M = 164		**1.03×10^{-05}**
^{165}Ho	stable	8.87×10^{-06}
Sum for M = 165		**8.87×10^{-06}**
^{166m}Ho	1200 y	0
^{166}Er	stable	1.41×10^{-05}
Sum for M = 166		**1.41×10^{-05}**
^{167}Er	stable	1.35×10^{-05}
Sum for M = 167		**1.35×10^{-05}**
^{168}Er	stable	0
^{168}Tm	93.1 d	0
^{168}Yb	stable	1.53×10^{-05}
Sum for M = 168		**1.53×10^{-05}**

Nuclide	Half-life	Content [g/g]
^{169}Tm	stable	7.60×10^{-06}
^{169}Yb	32.03 d	2.00×10^{-16}
Sum for M = 169		**7.60×10^{-06}**
^{170}Er	stable	2.25×10^{-08}
^{170}Tm	128.6 d	1.33×10^{-10}
^{170}Yb	stable	1.91×10^{-05}
Sum for M = 170		**1.91×10^{-05}**
^{171}Tm	1.92 y	2.51×10^{-08}
^{171}Yb	stable	2.26×10^{-05}
Sum for M = 171		**2.26×10^{-05}**
^{172}Yb	stable	1.49×10^{-05}
^{172}Hf	1.87 y	4.22×10^{-06}
^{172}Lu	6.7 d	4.14×10^{-08}
Sum for M = 172		**1.92×10^{-05}**
^{173}Yb	stable	1.75×10^{-05}
^{173}Lu	1.37 y	3.68×10^{-06}
Sum for M = 173		**2.12×10^{-05}**
^{174}Yb	stable	1.45×10^{-06}
^{174m}Lu	142.0 d	3.74×10^{-08}
^{174}Lu	3.3 y	1.12×10^{-06}
^{174}Hf	2.0×10^{15} y	2.36×10^{-05}
Sum for M = 174		**2.62×10^{-05}**
^{175}Lu	stable	3.83×10^{-05}
^{175}Hf	70.0 d	2.39×10^{-10}
Sum for M = 175		**3.83×10^{-05}**

Nuclide	Half-life	Content [g/g]
^{176}Yb	stable	3.12×10^{-08}
^{176}Lu	3.6×10^{10} y	2.20×10^{-06}
^{176}Hf	stable	4.20×10^{-05}
Sum for M = 176		**4.42×10^{-05}**
^{177}Hf	stable	4.80×10^{-05}
Sum for M = 177		**4.80×10^{-05}**
^{178}Hf	stable	2.22×10^{-05}
^{178}W	21.5 d	2.69×10^{-21}
^{178}Ta	9.31 m	8.09×10^{-25}
Sum for M = 178		**2.22×10^{-05}**
^{179}Hf	stable	1.49×10^{-05}
^{179}Ta	1.8 y	9.31×10^{-07}
Sum for M = 179		**1.58×10^{-05}**
^{180}Hf	stable	0
^{180}Ta	1.2×10^{15} y	8.63×10^{-07}
^{180}W	stable	2.25×10^{-06}
Sum for M = 180		**3.11×10^{-06}**
^{181}Hf	42.4 d	0
^{181}Ta	stable	8.33×10^{-07}
^{181}W	121.2 d	6.07×10^{-10}
Sum for M = 181		**8.34×10^{-07}**

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