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Isotopically Enriched ^{192}Os Target Preparation using the Electron-gun Beam Method at Target Preparation Laboratory, Daresbury, UK.

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Abstract

In this work, we have discussed a novel electron gun beam method used for the preparation of an Osmium foil sample at Daresbury Target Preparatory Laboratory, UK, which was used during the ^{192}Os(^{18}O, ^{16}O)^{194}Os 2 neutron transfer reaction at IFIN-HH Bucharest. The successful measurement of gamma energies associated with the ^{194}Os isotopic nucleus recorded from the experiment with the high resolution HPGe detectors from this clean target of ^{192}Os showed that this method has proven very efficient in preparing the most difficult osmium target which other methods like the sputtering, thermal evaporation could not get it prepared due to the high melting point of about 3000 ^{0}C found in the Osmium foil.

Introduction

Successes of experimental nuclear physics worldwide are strongly supported with a good nuclear target being produced from the laboratory to the specifications of the experiment to which it is going to be used. In the study of heavy ion reactions, however, isotopically enriched targets are in most cases the requirements for such reactions to be carried out. The design and preparation of these targets are visited often with difficulty because of the bristle and powdered nature of such of these targets. Vigorous efforts are therefore required in order to compress the powdered-form targets using different methods such as the electrodeposition (Chakrabarty *et al.,* 2001), general thermal evaporation, electron-gun beam methods, rolling, sputtering (Morrall, 2008) amongst other methods, into a film pellet substances with uniformity in dimensions across the entire (required) thickness of the prepared target (Morrall, 2008; Muggleton, 1979), thereby making the process a "nightmare".

The procedure followed during the preparation of an isotropically enriched ^{192}Os target for the experiment where the ^{192}Os target was to be bombarded with the ^{18}O to produce ^{194}Os through a 2 neutron transfer reaction (Daniel, 2017; Daniel, *et al.,* 2017) is not an exception from the listed challenges above. Owing to the fact that Osmium-192 isotope is one of the heaviest stable isotope (Fremlim and Walters, 1952) of the Osmium nucleus with 116 neutrons as compared to the other 6 stable isotopes (National Nuclear Data Centre) (details of the isotopic composition of Osmium is shown in Table 1), its preparation required special techniques other than just the normal thermal evaporation and other heating methods normally used during the preparation. Osmium is reported to have had quite a good number of unfavourable characteristics, such as being one of the hardest, densest metals, with melting point of about 3000 ^{0}C, electron gun beam method is usually recommended (Morrall, 2008; Maxman, 1967). One of the most popular ways of preparing an Osmium target is to convert the metal into an osmium tetraoxide OsO_4 by heating it in a stream of air or oxygen followed by dissolution of the resulting OsO_4 in suitable aqueous solutions (Chakrabarty *et al.,* 2001).

However, this method is very tedious and involved a long chain of processes. Osmium is known to have a high density and a brittle nature, making it almost impossible to roll it into thin foils. Hence, one of the ways that this would've again been possible is through sputtering and evaporation (Morrall, 2008), which even at this, the minute amount of the sample and low efficiency could not allow these methods of preparation for the isotopically enriched samples (Chakrabarty *et al.,* 2001). In this article, we explained the most convenient way by which this heavily ^{192}Os target with the presence of other chemical impurities as shown in Table 2 was prepared using the most effective electron gun beam method at Daresbury.

Table 1: The ^{192}Os Isotopic Composition (Trace Sciences International, USA, 2015; Rosman and Taylor ,1998)

nominal mass	accurate mass	% natural abundance	chemical form	% enrichment
^{184}Os	183.952488(4)	0.02(1)	metal	1+
^{186}Os	185.953830(4)	1.59(3)	metal	38+
^{187}Os	186.955741(3)	1.96(2)	metal	99+
^{189}Os	187.955830(3)	13.24(8)	metal	66+
^{189}Os	188.958137(4)	16.15(5)	metal	79+
^{190}Os	189.958436(4)	26.26(2)	metal	92-99+
^{192}Os	191.961467(4)	40.78(19)	metal	99+

Table 2: The ^{192}Os chemical impurities (Trace Sciences International, USA, 2015)

Element	Symbol	Impurity measurement (ppm)
aluminium	Al	500
calcium	Ca	100
copper	Cu	70
iron	Fe	500
magnesium	Mg	50
manganese	Mn	50
nikel	Ni	100
lead	Pb	50
platinum	Pt	50
silicon	Si	500
tungsten	W	100

Materials and Method

^{192}Os Target Making Procedure

The ^{192}Os target foil material, which was bought from the Trace company, USA (Trace Sciences International, USA, 2015) was prepared at the Daresbury Laboratory, UK, using the electron gun beam method (EGBM). Figure 1 showed the electron gun device at Daresbury used during the preparation of the ^{192}Os. The target foil of the ^{192}Os in a powdered form was weighed to appropriate grams to produce 20 mg/cm^2 thickness on the specification of the experiment. Target thickness can be obtained in two different ways namely: (i) through the determination of the ratio of the target foil mass to the measured surface area (Chakrabarty *et al.,* 2001, Morrall, 2008) and (ii) uniformity measures of the foil, thereby observing the changes in energy of the charged particles through the target foil (Morrall, 2010). Other prerequisites considered aside the thickness of the target during preparation are subjects to the recommendation of the experiment, which include the followings: the uniformity, type of the target frame (which determines the target shape and surface area, see Figure 3), isotopic composition and/or material (see Table 1 for details), self supporting foil, backing and its thickness (Morrall, 2010; Florea *et al.*, 2015).

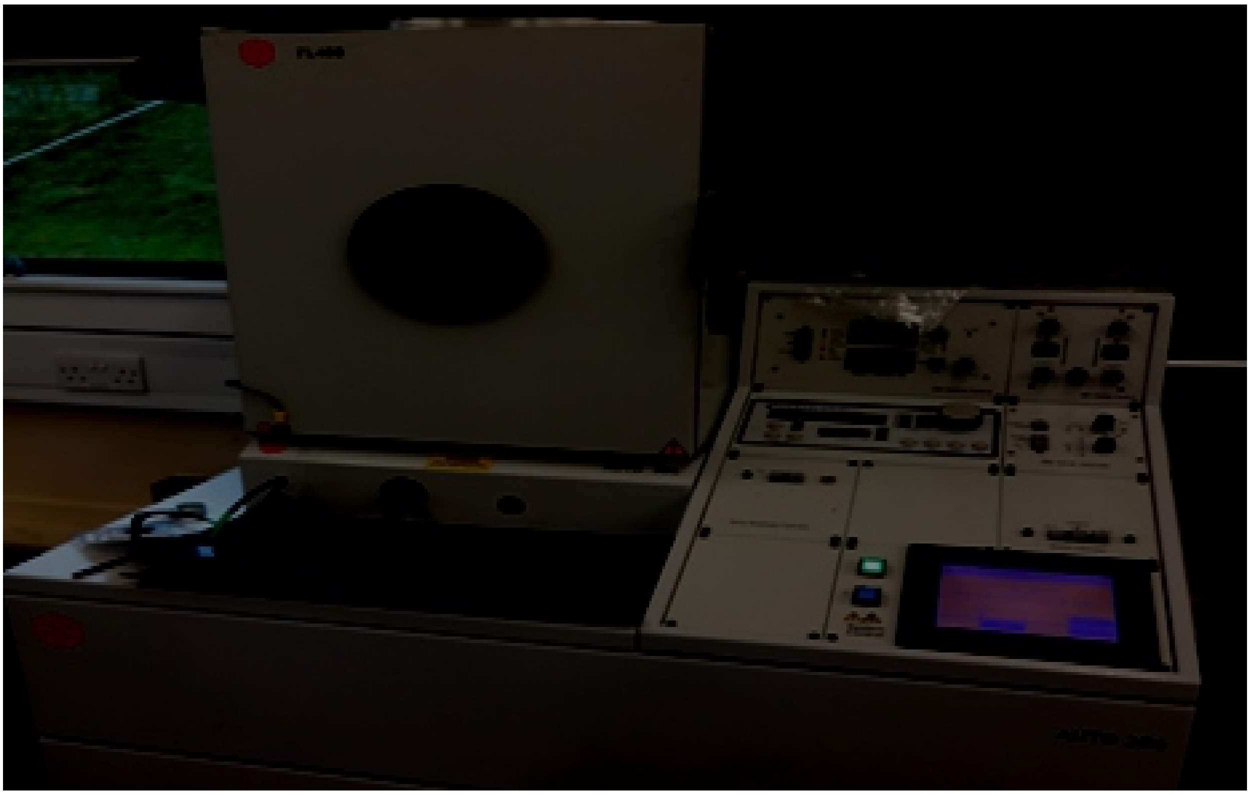

Figure 1: The electron gun device at Daresbury Laboratory, UK, used during the ^{192}Os target preparation.

Target requirements in nuclear experiments have pushed the limits for the target preparation techniques (Morrall, 2010). The making of the ^{192}Os target foil for the first 2^+ state half-life measurement in ^{194}Os (Daniel, 2017; Daniel, *et al.,* 2017) was done using an electron gun beam method (Morrall, 2010).

In this study, the thickness of the target foil was not the key requirement, but the purity of the target foil as specified by the experiment. During the process of preparation, a certain quantity of the powder sample of the ^{192}Os metal was put on the pellet of 13 *mm* diameter and placed in a Di-press holder which was transferred to the Ultrasonic bath (see Figure 2 for details) for half an hour in order to obtain uniformity in the sample as it spins round.

Figure 2: The Ultrasonic bath device at Daresbury laboratory, UK.

More pressure was applied to the powdered foil to remove the surrounding air, after which the pellet was subsequently removed from the ultrasonic bath and was taken to the hydraulic pressure pump where 4 tonnes of pressure was applied for 30 minutes. When the pellet attained a pressure of $10^{-5} - 10^{-6}$ mbar in the vacuum pump, it was then transferred to the EGB device, for a period of 12 hours. At this time, 5.00 kV voltage was maintained with a current of 0.51 mA for the first 30 minutes, thereby introducing further heating to the pellet. At this point, the target was allowed to cool and was later mounted on the target frame as shown in Figure 3, ready for use.

Figure 3: The final processed ^{192}Os target (showing little black spots on the holder) mounted on the gold frame.

The ^{192}Os Target Storage

Since targets are very delicate and fragile, the storage of these "precious" experimental ingredients is usually recommended based on the type prepared and for specific reasons. In this case, and by considering the fragile nature of the final ^{192}Os produced target, a special storage device known as the vacuum flask or the gold frame was provided for the final prepared target to be stored in so as to avoid moisture contaminations and evaporation of the prepared target material. And ^{192}Os target was finely covered in a gold metal shielding as shown in Figure 3.

Results, Conclusions and Recommendations

The ^{192}Os target produced was used in the ^{192}Os(^{18}O, ^{16}O)^{194}Os 2 neutrons transfer at IFIN-HH Bucharest with 80 MeV beam energy. The collected data was sorted using both RADware and GASPware (Daniel, 2017) and the resulted 2D energy projection spectra from coincidence techniques was obtained as presented in Figure 4.

The identified nuclei energies were done with the aid of NNDC data (National Nuclear Data Centre, 2017) in a coincidence analysis. This technique is very powerful such that whenever two or more energies appear in a selection as 'coincidence' using either two or more energy-fold, the nuclei is looked up at the NNDC website for identification. This has been proven very efficient in this research where all the identified nuclei and with their energies in the experiment done with the ^{192}Os target are compared with the online data as presented in Figure 4 (Daniel, 2017 and Daniel et al., 2017).

Details of the nuclei identified in the experiment with the 192Os target produced as as shown in Figure 5 (Daniel, 2017).

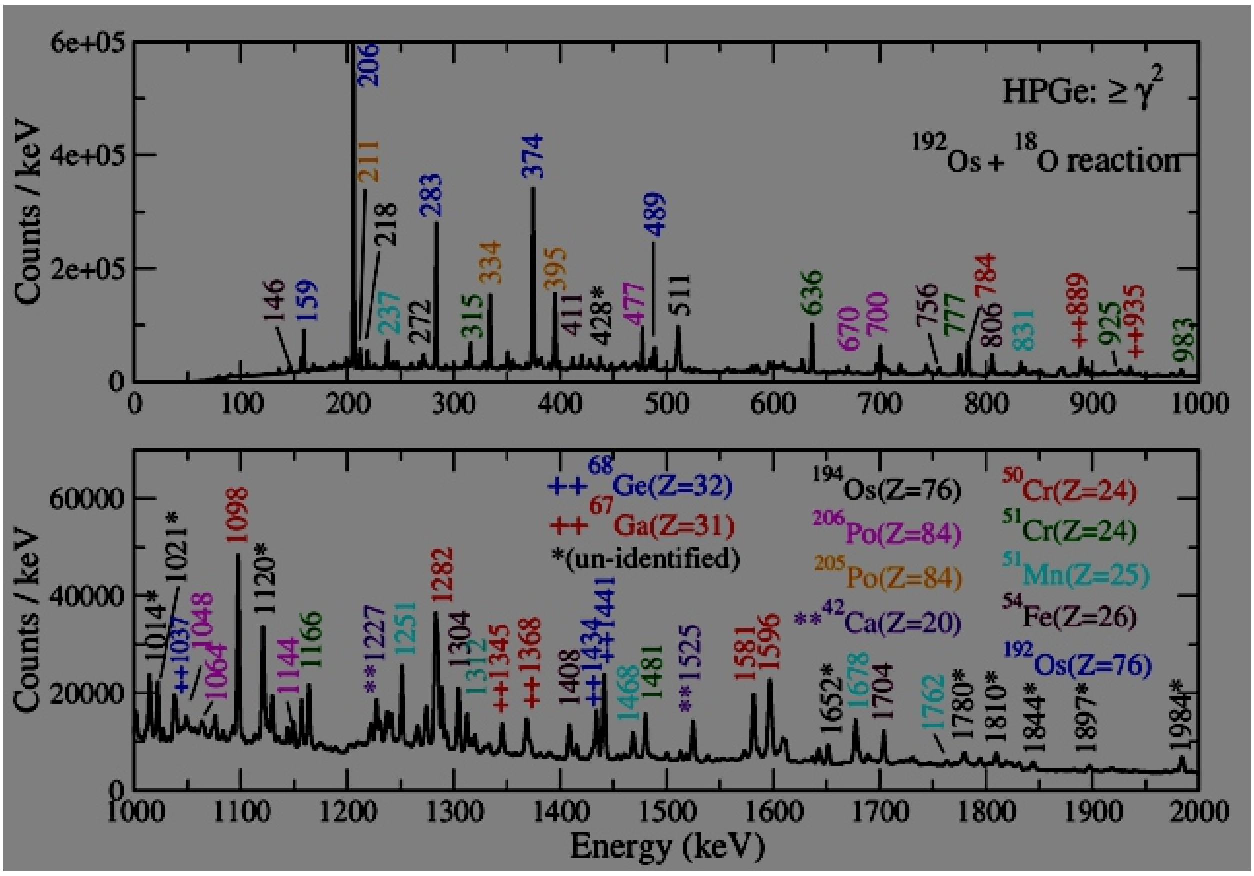

Figure 4: Total HPGe projection spectrum (γ–γ HPGe coincidence software trigger condition) from the ^{192}Os + ^{18}O reaction at an incident beam energy of 80 MeV. The dominant channel is from Coulomb excitation (CouLex) of ^{192}Os identified in blue. Other identified nuclei in the total projection are fusion channels from the target and chemical impurities (eg. ^{40}Ca, ^{28}Si) reacting with the beam nuclei of ^{18}O (Daniel, 2017).

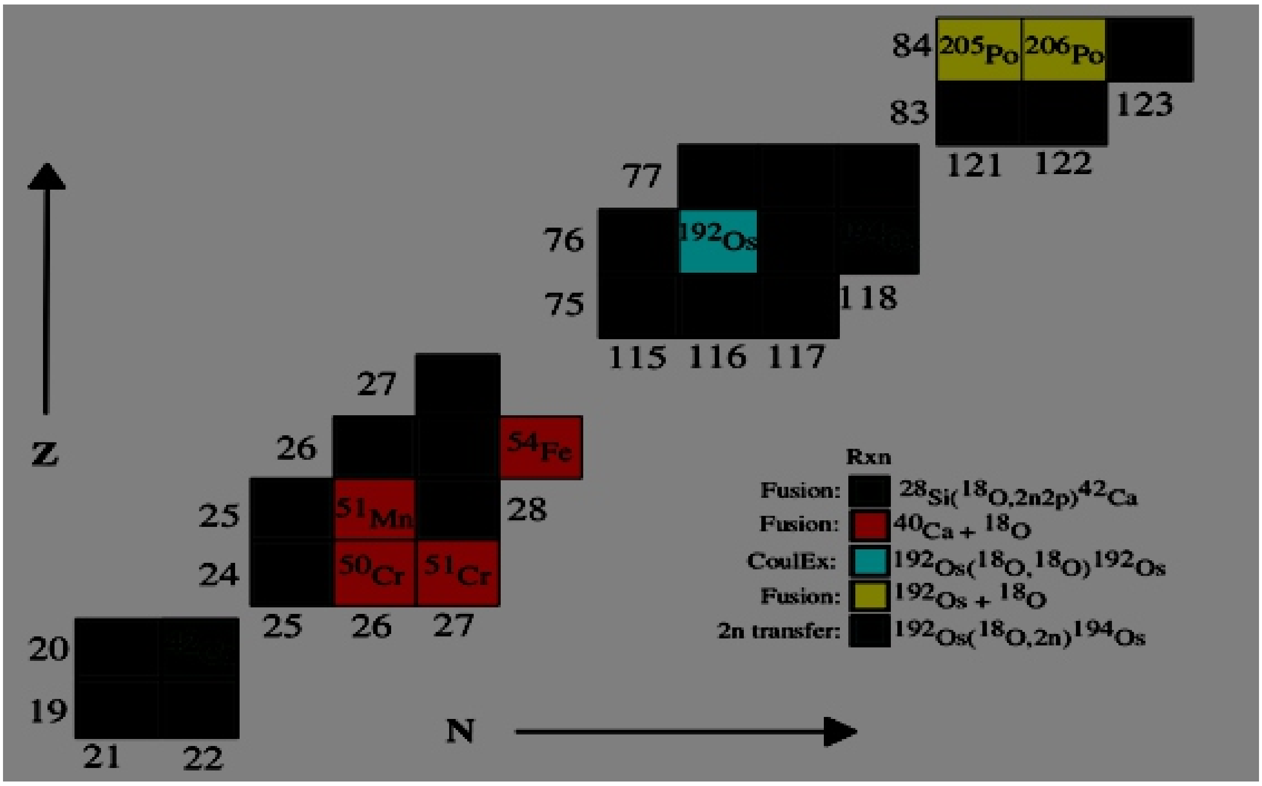

Figure 5: Schematic partial chart of the nuclides noting the various residual nuclei observed in the current work. The yellow boxes represent fusion evaporation channels from the ^{192}Os + ^{18}O reaction; the green box represents products from the ^{28}Si + ^{18}O reaction; and the red square-boxes are residues from fusion channels from ^{18}O beam on ^{40}Ca target.

The importance of nuclei targets during any nuclear experiments as well as their importance as it relates to the success of such nuclear experiment are enormous, and as such should be considered the top most priority of any nuclear Physics research for completeness and accuracy of data that will be obtained for analysis.

In this work, it has been observed that targets that are hard in nature with melting point of 2000 ^{0}C to almost 3500 ^{0}C are most suitably prepared using the electric gun beam method.

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References

Chakrabarty, S; B.S. Tomar, A. Goswami, V.A. Raman , and S.B. Manohar (2001), *Preparation of thin osmium targets by electrodeposition;* Nuclear Instruments and Methods in Physics Research B 174, 212 – 214.

Daniel, T. (2017), *Nuclear Structure studies of low-lying states in 194Os using fast-timing coincidence gamma-ray spectroscopy*; Ph.D Thesis Submitted to the University of Surrey, Guildford, UK.

Daniel, T., Kisyov, S., Regan, P. H., Marginean, N., Podolyak, Zs., Marginean, R., K. Nomura, M. Rudigier, R. Mihai, V. Werner, R. J. Carroll, L. A. Gurgi, A. Oprea, T. Berry, A. Serban, C. R. Nita, C. Sotty, R. Suvaila, A. Turturica, C. Costache, L. Stan, A. Olacel, M. Boromiza, and S. Toma (2017), *γ -ray spectroscopy of low-lying excited states and shape competition in ^{194}Os;* PRC 85, 024328, 1 – 9.

Florea, N. M., Stroe, L., Marginean, R., Bucurescu, D., Costache, C., Lica, R., Marginean, N., Mihai, C., Mosu, D. V., Nita, C. R., Pascu, S., and Sava, T., (2015), *The status of the preparation laboratory at IFIN-HH Bucharest, Romania*; Journal of Radioanalitical and Nuclear Chemistry, 305, 707.

Fremlim, J. M., and Walters, M. C., (1952), *An Experimental Investigation of the Stability of Nuclei against Double Beta-Disintegration;* Proc. Phys. Soc. A 65 911 – 915.

Maxman, S. H., (1967), *Target preparation techniques*; Nuclear Instruments and Methods, 50, 53 – 60.

Trace Sciences International, www.tracesciences.com, *USA, 2015.*

Morrall, P. S. (2008), *The Target Preparation Laboratory at Daresbury;* Nuclear Instruments and Methods in Physics Research A 590, 118–121.

Morrall, P. S., (2010), *Target preparation method and characterisation;* Nuclear Instruments and Methods in Physics Research A 613, 423–424.

Muggleton, A. H. F., (1979). *Preparation of thin nuclear targets*; Journal of Physics E: Science Instruments, 12, 780 – 807.

National Nuclear Data Centre; https://www.nndc.bnl.gov/ensdf/DatasetFetchServlet.

Rosman, K. J. R., and Taylor, P. D. P., (1998), *Isotopic Compositions of the Elements 1997;* Pure and Applied Chemistry, 70, 217.