Revista Brasileira de Aplicações de Vácuo, Vol. 17, nº 1, 1998

DESCRIPTION OF SOME METHODS TO FABRICATE NUCLEAR TARGETS DEVELOPED IN THE TARGET LABORATORY OF THE UNIVERSITY OF SÃO PAULO

Nobuko Ueta* and Wanda G. P. Engel
* Fax:(011)211-2742-E-Mail: nueta@upif1.if.usp.br.
Dpt Física Nuclear, Instituto de Física, Universidade de São Paulo - SP
Caixa Postal: 66318 - CEP: 05315.970 - São Paulo

Key-words: Nuclear target, vacuum evaporation, thin film.

Abstract - The usual methods to fabricate thin films used as nuclear targets are described. Some important details are pointed out.

Resumo - Estão descritos os métodos usuais de fabricação de filmes finos utilizados como alvos nucleares . Alguns detalhes importantes do procedimento serão mostrados.

1. Introduction

There are many usual methods to fabricate nuclear targets that are described in the literature in a few books[1,2], as well as in several review articles[3,4,5] and in specific articles the references of which are collected elsewhere[6]. Starting from the suggested methods it is necessary to develop our own receipt, even if a detailed description is found in the literature. There must be some unknown important parameter involved in the target fabrication, so that the method is not completely reproducible in different evaporation units. In this paper a review of the usual methods of fabrication will be given and some general procedures learnt during the developments carried out in our laboratory will be pointed out. Some other details are found in specific articles which are referred to throughout this article.

2. The usual methods used in our laboratory

2.1 The appropriate choice of the method

The vacuum evaporation method is suitable to prepare most of the requested targets, which have usually the thickness of hundredths of mg/cm^2 (~ thousands of Å). When stopper foils or thicker targets of the order of mg/cm^2 are needed, the appropriate method is the rolling. Eventually targets of intermediate thickness are needed. Nevertheless, it is known through many negative attempts that too thick targets, of tenths of mg/cm^2, are difficult to be obtained by vacuum evaporation. The material begins to peel off or the film tears when a certain amount of material is accumulated. On the other hand, it is not easy to obtain mechanically stable thin films of much less than 1 mg/cm^2 by the rolling method even if annealing of the material is performed during the thinning procedure.

If the presence of certain nuclei, for example C or O, is not acceptable or even forbidden, the appropriate handling in all stages of the target making method must be carried out, in order to avoid the undesirable contamination. The vacuum evaporation method is, in general, the cleanest process mainly if a cryogenic-pump is used. The targets must be evaporated directly on suitable backings and are covered with a thin layer of Au.

2.2 Preparation of the substrates.

It is necessary to find out which substrate must be used to obtain a homogeneous and mechanically stable target thin film. The chemical structure as well as the physical structure of the substrates affect the quality of the thin film deposited onto them. The search is usually done using different substrates when the first test run evaporation is carried out. Usually, the material is evaporated on previously cleaned and polished glass slides, where a very thin layer of a special detergent (RBS) coating is left. In some cases a thick layer with stripes is necessary. In other cases the detergent layer must be rubbed on the glass slides doing circular movements. As this layer is soluble in water self-supporting targets, which are not soluble in water, can be made by floating off the thin film pieces on a water bath and mounted on appropriate target frames. If the target material is soluble in water or if there is no need of a self-supporting target, thin C or Al films are mounted on target frames, which are used as the substrates to receive the target material. Usually, these are mechanically more stable than the self-supporting ones. The pre-cleaned glass slides are commercially available but to avoid importation one follows an old method doing the polishing and cleaning process manually. The glass slides are first washed one by one with a detergent ,then immersed in a bath of iso-propilic alcohol. Once dried they are polished using the Balzer's cleaner n.1. The product is removed using a smooth paper. Then, the Balzer's n.2 cleaner is used one by one on the glass slides until they become with the appropriate polishing.

2.3 The electron bombardment method

This method is used in the Edwards E12E3 evaporation unit which is an almost 30 years old equipment[7]. The electron beam emitted by a W circular filament can be focused on the target material, located in an appropriate crucible, adjusting the relative distance mechanically.

Several different materials can be loaded in separate crucibles mounted on a serrated plate, which is movable without breaking the vacuum. One metallic chain is coupled to the serrated plate and permits both movements. A schematic view of the apparatus is shown in figure 1.

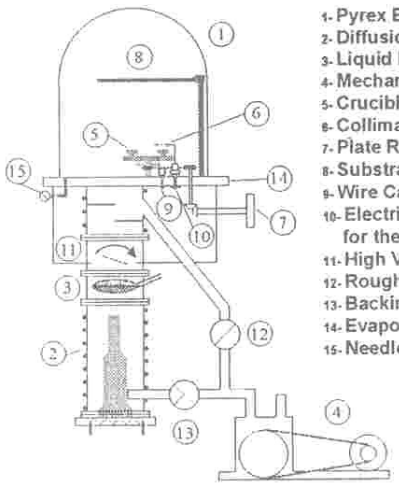

Fig.1 Electron bombardment

In this method it is crucial to find out the appropriate combination of the chemical compound and crucible material , which will not contribute with undesirable contaminants in the nuclear measurements, as well as the best geometry. There are crucibles of many different cylindrical shapes ,shallow or deep, usually with a thin wall and the diameter varying from 3mm to 8mm . In some cases only a small dimple on the top of the cylinder is sufficient and appropriate to lay the material. The shape of the crucible and the distance between the vapor source and the substrate define the total area and the uniformity of the material deposition. The suitable shape as well as the material (for example W, Mo, Ta, inox, C) varies considerably and each crucible is manufactured for a specific target. The deep and thin diameter crucibles will show a reduced emittance giving a good efficiency of material consumption, but on the other hand, care must be taken so that a suitable thickness uniformity is attained. The efficiency of material consumption is measured by the comparison of weights of the crucible and substrates before and after the evaporation is performed. The best efficiency of material consumption must be searched because it is usually necessary to evaporate isotopically enriched material. All the test runs are made using chemically pure compounds and once the ultimate method is attained the enriched material is used. There are many materials which are known to form an alloy, in high temperature, with the crucible material. The formation of an alloy reduces the efficiency, but, when the evaporation temperature of the alloy is much higher it does not contribute with contaminants. If this happens, in a first run there is the formation of an alloy, then a new load of material is provided to evaporate it to get the required target.

The electron bombardment method is usually chosen when only a small amount of material is available and when expensive or rare material must be used. This method is also more suitable to evaporate materials which have a high evaporation temperature because the appropriate crucible can be made. Up to 6 different materials can be evaporated subsequently without breaking the vacuum to fabricate multi-layer targets.

2.4 The Joule heating method.

This method consists of the heating of the material, laid on metallic containers, through the passage of an appropriate amount of electric current. An adjustable and simple power supply is necessary. Filaments or boats of different shapes and materials are used as shown in figure 2. Al and Au are usually evaporated hanging small pieces of the metal wire on the filament. It is usual to evaporate different salts which are used as release agents, for example, CsI, NaCl, $BaCl_2$, by loading an amount of the chosen compound on the boats. The nuclear target element is sometimes available as an oxide or as a salt in powdered form . When larger quantities (tens of mg) can be used in each loading of material, it is possible to try the evaporation by this method. Powdered material can have absorbed humidity and must be slowly heated in vacuum to loose water without causing lost of material. If the heating procedure is carried out too rapidly the powder grain will jump out from the boat. There are some boats provided with a perforated lid, but then a visual control of the evaporation cannot be done. Also in this method, some materials can form an alloy with the boat metal, which is undesirable because of the target contamination. Some oxides are reduced by the metallic boat resulting in a small content of oxygen on the target. The target material vapor reaches a large area so that many targets can be made at once. The larger the distance between the substrate and the boat, the better the deposition uniformity in a small area. In general, this method is less efficient in material consumption when large distances are used compared to the electron bombardment method. It is evident that the geometry of the boats and crucibles affects drastically on the emittance and the efficiency. There are some sophisticated geometry boats for the Joule heating method, which are commercially available, with a smaller emittance area, but usually for a very large amount of material.

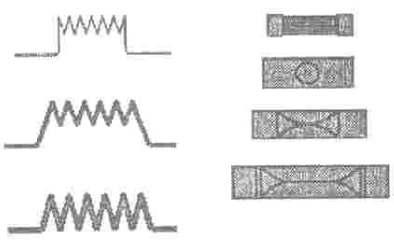

Fig.2 - Joule heating filaments and boats

2.5 Carbon - arc method.

The carbon-arc method is very simple and needs only some trivial electronics. It has been used with success over the time and has got some modifications. Thin carbon films are used also as stripper foils in Tandem accelerators. Therefore, many researches have been carried out to attain thin long-lived stripper foils, specially using carbon-arc method. A detailed choice of the glass slides as well as a very careful and sophisticated handling of the substrates was recommended[8,9].

The C-arc apparatus is mounted in an NRC evaporation unit and is schematically shown in figure 3. The distance between the two carbon electrodes(5) is controlled through the handle(9), the gears(10) and the endless screw (11) which has the screw-thread in opposite direction on the left and on the right halves. The Pyrex bell-jar has a 45 cm diameter and 70 cm height. The vacuum of 10^{-3} Pa is obtained by a 6"CVC diffusion pump and an Edwards E2M18 mechanical pump.

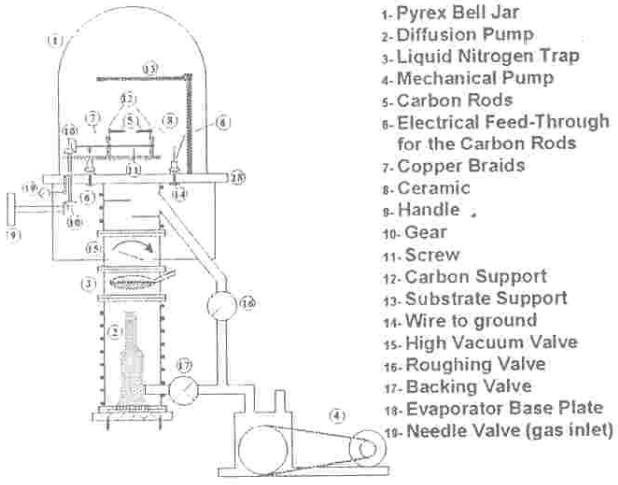

Fig.3 - C-Arc method

The carbon rods are Balzer's 3mm thick, 3 to 5 cm long pure carbon, sharpened on one end only as shown in figure 4. The previously polished glass slides with a thin layer of a release agent are used as substrates. For thin C films the better results were obtained with RBS as the release agent, or with CsI evaporated directly on the glass slides or with CsI evaporated on a layer of RBS. Different thicknesses of the release agents affect the mechanical stability of the film. Although NaCl is very frequently used as a release agent there has been no acceptable result in the performed attempts. Chemically pure salts has been used. The heating of the substrates is possible using a 500W lamp located just above the glass substrates and the temperature can be read indirectly through the voltage across a series of diodes, located just beside them and maintained in a constant current circuit. The stripper foils as well as the carbon films used as target backings are fabricated by the electron bombardment unit or by the carbon-arc method.

Some modifications in the procedure using the arc discharges interchanging AC and DC power can be found in the literature [10]. Those procedures result in carbon films with differences in the structure as presented in detailed analysis[11,9] and longer life times, but are not yet used in our system.

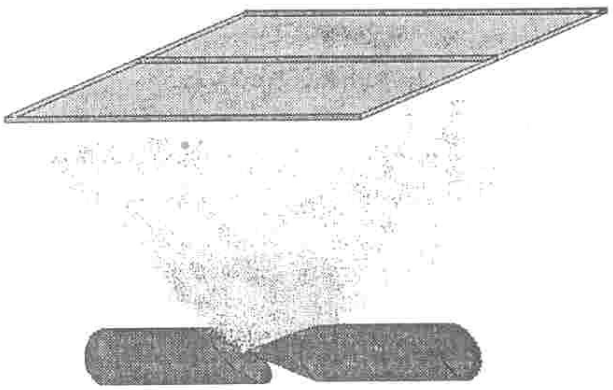

Fig.4 - Shape of the Carbon rods

2.6 Rolling

The relatively thick (>1mg/cm^2) nuclear targets and particle stoppers are usually made by rolling a piece of wire or of a sheet of the required material using a rolling mill. The rolling is performed by successively thinning the material laid inside a folded strip of a polished and treated piece of inox steel. The pressure on the rolls is raised at each step. There has been many reports about a commercially available mirror finished steel in stripes which are protected by an attached plastic foil [20,31,32].As this special finishing was not usual in our country the polishing and the cleaning has been performed manually. The folded strip is rolled first many times and then the material is located inside it. The material is turned by 90^0 inside the folded steel piece lifting gently the foil using tweezers. If a rupture appears at the edge of the foil , the central part is saved using a pair of scissors trying to choose the good part in square format. In some cases a droplet of diffusion pump oil is used to prevent the undesirable attachment of the foil to the steel.

3. Some other existing methods.

There are several other methods commonly used, some of them with better results concerning the efficiency in the material consumption. A brief description of the useful methods for our purpose will be given.

3.1 Electron-bombardment with electromagnetic beam deflection.

As the pure material required for the fabrication of nuclear targets is very expensive, in particular when isotopically enriched material has to be used, the efficiency in the material consumption and the absence of undesirable contaminants must be taken into account in the development of the method. In the electron-bombardment unit with electromagnetic beam deflection there is the possibility to focalize the electron beam into a spot and to sweep the beam in two orthogonal directions, so that a good focus exactly on the target material can be attained. Therefore it is expected that better nuclear targets can be obtained by this method. However, in some machines the cross-sectional area of the electron beam is too large, which is a restriction when small amount of material is available. There has been a suggestion to make a pill of the material in order to concentrate it locally. There has also been a report about the collimation of the electron beam to reduce its cross section [12]. Nevertheless, many good quality nuclear targets have been produced in the most important research centers as reported in the world conferences of the International Nuclear Target Development Society[13].

3.2 Sputter deposition using fine beam ion source.

The use of simplified fine beam saddle-field ion source was reported[14] with the advantage of compactness, simplicity of operation and overall economy. The targets are obtained with the substrate just above the material at a distance of 3 cm. The ion source was operated with Ar or N gas. The use of Xe beam sputter deposition was also reported[15] and has been used for many different target materials[16,17]. A schematic view of the system is shown in figure 5.

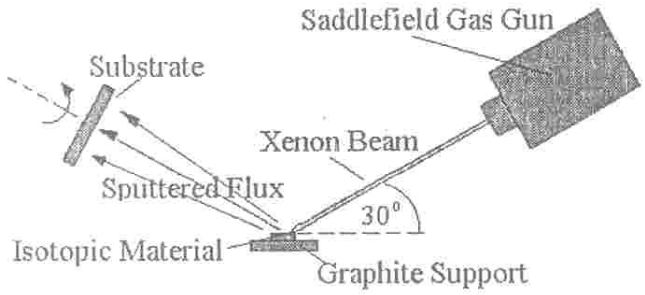

Fig.5 - Xe beam sputter deposition method

The main disadvantage of this method is the low deposition rate compared to the previous one. But, the efficiency of material consumption and the absence of contaminants are remarkable. The ion beam has been used also for thinning targets to reach the desired thickness[18], when by rolling method the target would be too thick and by evaporation too thin. There is a commercially available sputter deposition device, where an electron beam is used to sputter large amounts of material for a very large deposition area. There are also RF sputtering devices. These devices can afford a high deposition rate but are not suited to our purposes. In the Ar or Xe beam sputter deposition device, the beam is very concentrated and is controlled to reach the small amount of the required target material.

3.3 Special rolling methods.

There are some targets which are made by the rolling of a bead, which is obtained through the reduction of an oxide and the heating of the metal in vacuum. There is a specially developed process for each particular case[19]. Hot rolling is recommended in some cases using the material inside a mirror finish stainless-steel outer pack[20]. When a metal with strong tendency to oxidize is used, the rolling must be performed inside a glove box in dry argon atmosphere and the obtained target must be stored in vacuum chambers[21].

There has been many other related processes in the world conference of the INTDS[13] or in earlier conferences[6].

3.4 Electrodeposition

Rare earth nuclear targets and radioactive nuclide targets have been prepared by electrodeposition. The apparatus shown in figure 6 consists of a deposition cell with a body made of insulating material , where the suitable acid solution is poured, an anode and a metallic cathode, which is the substrate of the target. A high voltage supply is necessary and the applied high voltage as well as the current depends on the geometry and on the acid concentration used in the deposition cell[22,23]. Some radioactive targets have been made by this method. There are some recommended procedures to be followed to prevent from personal contamination. There are some recent reports on laboratories where radioactive targets and sources are obtained by vacuum evaporation [24,25]. A complete hot laboratory has been mounted to account for all necessary personal radiation protection rules . The advantage of the vacuum evaporation method is the absence of undesirable contamination.

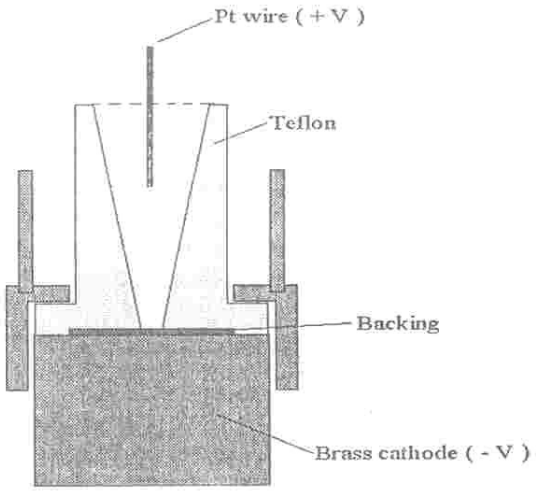

Fig.6 - Electrodeposition

4. Some remarks

4.1 Some strategies to avoid contaminants.

The most common contaminants are C , N , O , Ta , W , Mo, and the contaminants which come with the chemical compounds used in the evaporation. Once a specific nuclear reaction is chosen, it is necessary to identify all impurities which are forbidden to be present in the target. Although vacuum evaporation process is the cleanest process there are some procedures to be followed. The better vacuum in the evaporation unit ensures the least presence of contaminant residual gas. A glow discharge with a small amount of Ar cleans the system substancially. But this process must be avoided when the substrates are already mounted by closing the shutter between the crucible and the substrates.

A new filament and a new boat or crucible to be used in the system must be previously heated to expel the adsorbed gases and to clean them from oxides. This is also the case for some materials which are used to make the targets , as has been already pointed out .

The type of oil used in the diffusion pump as well as in the rotary pump must be carefully chosen even when a liquid nitrogen trap is used . The contamination with Si was eliminated substituting the Octoil S by the Neovac SY oil. The cleaning of the evaporator pieces with sand jets , every time a new element is used , must be followed by a thorough washing with water and rinsing with water and alcohol to remove all residues. The drying is carried out in an oven.

To avoid the residues of the release agent used on the glass substrates , the floating process is carried out using clean distilled water. When a salt is used as release agent warm distilled water is used and is renewed frequently.

4.2 The target storage

It is known that some targets must be made just before the beam time because they do not have a long time stability. Small spots appear on the surface of the target. There are some evidences that if a target is made from a salt of the chosen element , it is possible a recombination with the CO_2,NO_2 or $SO_4$of the atmosphere to return to its former chemical compound. Some elements are known to oxidize very easily as Ca , Al , Ag ,etc. In almost all targets a small amount of Au is deposited to be used in data normalization but it is useful also to avoid the unwanted chemical recombination.

Some small inox steel chambers are provided with a valve so that the targets can be stored in vacuum or in Ar or N_2 pure and dry gas in atmospheric pressure. The sensitive targets are stored in those chambers and a visual control can be made through the glass lid . In some cases even with those special cares it is not possible to maintain the targets for a long period.

4.3 The temperature of the substrates

In the cases where the sublimation temperature is very high , it is possible that the over heating of the substrates occurs damaging the release agent layer during the evaporation of the target material .Then the target thin film will not loosen from the substrate. If self-supporting targets are needed the substrates must be cooled using a cover of copper plate refrigerated with flowing cold water. In some cases the use of a very cold thick copper plate is enough. If the target may have C or Al the material may be evaporated on these substrates already mounted on target frames. There has been some cases that a smaller diameter mask in front of the target frames gave good results of adherence and stability.

There are other cases where a heating of the substrates is necessary to release the film from tensions and to permit the easier migration of the molecules during the film formation. The heating is carried out using a 500W lamp just on the substrate.

5. The parameters used in the laboratory.

In the table 1, included at the end of this article, it is shown the parameters used in our laboratory to obtain the requested nuclear targets. Some of the target fabrication methods were developed together with the interested researchers as shown by the references. In a previous review article [7] some of these parameters were published.

6. Acknowledgments.

The authors wish to express their thanks to all the technicians and researchers of the Pelletron Accelerator's staff. In particular, to Mr. J. C. de Abreu and Mr. W. Bruzinga for their everyday dedicate work when they composed the target laboratory's staff. To Mr. J.J.G. Leandro, who has been working in the target laboratory since 1996, the authors are indebted for the drawings and efficient collaboration. This work has been partly supported by the Financiadora de Estudos e Projetos (Finep), by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and the Fundação de Amparo a Pesquisa do Estado de São Paulo(Fapesp).

7. References

1. L.Holland - "Vacuum Deposition of Thin Films" 6th printing , Ed. Chapman and Hall Ltd, 1970.
2. L: Eckertová - "Physics of Thin Films " 2nd edition, Plenum Press, 1986.
3. A. H. F. Muggleton, J. Phys. E: Sci. Instrum. vol. 12 (1979)780-807; A. H. F. Muggleton, Nucl. Instr. & Meth. in Phys. Res. A334(1993)3-15.
4. S. H. Maxman, Nucl. Instr. & Meth. 50(1967)53-60.
5. L. Yaffe, "Preparation of thin films, sources and targets". Annual Review of Nuclear Science, vol. 12, 153 -188.
6. J. C. Gursky and M. S. Peacock - Index of Publications of the International Nuclear Target Development

Society. Los Alamos National Laboratory - LA-UR 2097. Ch. Louvrier and P. Robouch; Nucl. Instr. and Meth. in Phys. Res. A334(1993)222-225 and a computer disket.

7. N. Ueta and W. G. P. Engel - Nucl. Instr. and Meth. in Phys. Res. A282(1989)188-190. N. Ueta, W. G. P. Engel e J. C. de Abreu, Rev. Bras. de Aplic. de Vácuo vol. 10(1991)81-84.
8. S. Takeuchi, C. Kobayashi, Y. Satoh, T. Yoshida, E. Takekoshi and M. Maruyama - Nucl. Instr. and Meth. 158(1979)333-338.
9. S. Takeuchi and S. Kanazawa - Nucl. Instr. and Meth. 197(1982)267-272.
10. I. Sugai, T. Fujino, K. Yamazaki, T. Hattori and M. Ogawa; Nucl. Intr. and Meth. in Phys. Res. A236(1985)576-589.
11. I. Sugai, T Hattori, H. Suzuki, H. Kinoshita, H. Kato and K. Yamazaki; Nucl. Instr. and Meth. in Phys. Res. A265(1988) 376-382.
12. G.E. Thomas, J. P. Greene, P. Maier-Komor and R. H. Leonard; Nucl. Instr. and Meth. in Phys. Res. A303(1991)162-164.
13. Proceedings of the 15th World Conference of the International Nuclear Target Development Society - Nucl. Instr. and Meth. A303(1991)1-208; Proceedings of the 16th World Conference of the International Nuclear Target Development Society- Nucl. Instr. and Meth. A334(1993)3-258; Proceedings of the 17th World Conference of the INTDS, Nucl. Instr. and Meth. A362(1995)1-216.
14. A.H.F. Muggleton; Nucl. Instr. and Meth. in Phys. Res. A303(1991)157-161.
15. H. J. Maier; Nucl. Instr. and Meth. in Phys. Res. A303(1991)172-181.
16. H. J. Maier, H. U. Friebel, D. Frischke and R. Grossmann; Nucl. Instr. and Meth. in Phys. Res. A334(1993)137-141.
17. A. Méens and G. Ehret; Nucl. Instr. and Meth. in Phys. Res. A362(1995)53-59.
18. G.E. Thomas and J. P. Greene; Nucl. Instr. and Meth. in Phys. Res. A334(1993)132-136.
19. R. Pengo, P. Favaron, G. Manente, A. Cecchi, L. Pieraccini; Nucl. Instr. and Meth. in Phys. Res. A303(1991)146-151. G. Manente and D. Blunt ; Nucl. Instr. and Meth. in Phys. Res. A362(1995)94-97.
20. W. R. Lozowski, J. Hudson and W. A. Dezarn; Nucl. Instr. and Meth. in Phys. Res. A362(1995)189-193.
21. H. J. Maier - Nucl. Instr. and Meth. 200(1982)113-120.
22. M. M. Fowler, J. C. Gursky and J. B. Wilhelmy; Nucl. Instr. and Meth. in Phys. Res. A303(1991)99-101 and references there in.
23. A. Cecchi; Nucl. Instr. and Meth. in Phys. Res. A303(1991)102-105. A. Cecchi and P. Sona, Nucl. Instr. and Meth. A282(1989)110.
24. J. P. Greene, I. Ahmad and G. E. Thomas; Nucl. Instr. and Meth. in Phys. Res. A334(1993)101-110.
25. R. Grossmann and H. J. Maier; Nucl. Instr. and Meth. in Phys. Res. A334(1993)83-87.
26. K. Koide, H. Takai, M. M. Coimbra and O. Dietzsch; Nucl. Instr. and Meth. in Phys. Res. A370(1996)341-344.
27. D. Pulino, G. M. Sipahi, G. M. Ukita, T. Borello - Lewin, L.B. Horodynski - Matsushigue, J. L. M. Duarte, W. G. P. Engel e J. C. de Abreu. Rev. Bras. de Apl. de Vácuo vol. 10 n.2(1991)87-90.
28. W.G. Engel, J.J.G. Leandro and N. Ueta - work presented in the XVIII CBRAVIC , 1997, submitted to publication.
29. N. H. Medina, R. V. Ribas e J. C. de Abreu; Rev. Bras. de Apl. de Vác. Vol. 10, n2(1991)65-68.
30. W.G. P. Engel, J. C. de Abreu and N. Ueta; Rev. Bras. de Aplic. de Vácuo, vol. 15(1996)24-26.
31. Manente and D.Blunt;Nucl. Instr. and Meth. in Phys.Res. A 362(1995)94,97.
32. J.P. Greene and G. E. Thomas Internal publication of the Argonne National Laboratory, Universtity of Chicago PHY-8557-HI-96, June 1997 and G. E. Thomas and J. P. Greene, Nucl. Intr. and Meth. in Phys. Res. A. 362(1995)201, 204.

Table1 (1/3) Parameters used to fabricate nuclear targets.

Atomic Number	Element	Thickness $\mu g/cm^2$	Backing	Method	Chemical compound	Crucible(eb) Boat (jh)	Power (W) Current (A)	Parting Agent	Observations References
5	^{10}B, ^{11}B	20 on 30	s.s.	e.b.	B lump	Cermet	100W	BO	26 28
5	^{10}B, ^{11}B	20	Al	e.b.	B lump	Cermet	100W		28
6	^{12}C	15	glass-fiber rings	arc	C rod	----	400W	----	----
6	C	5-8	s.s.	arc	C rod	----	400W	RBS or CsI	stripper
6	C	5-10	s.s.	e.b.	C rod	C	>100W	RBS	stripper
6	C	20-30	s.s.	e.b.	C rod	C	>100W	RBS	backing
6	C	20-30	s.s.	e.b.	C rod	C	>100W	betain	backing
8	O	100-500	Al	e.b.	SiO_2	Ta	100W	----	boat with a lid
12	^{24}Mg	20-30	C+Bi	e.b.	MgO	Ta	50-60W	RBS	----
13	^{27}Al	500-800	s.s.	j.h.	metal	W	2.5 - 3.0	RBS	----
13	^{27}Al	30	s.s.	j.h.	metal	W	2 - 2.5	RBS	----
13	^{27}Al	80	mylar	j.h.	metal	W	2.5 - 3.0	RBS	----
13	^{27}Al	750-1400	s.s.	rolling	----	----	----	RBS	----
14	Si	300	C	e.b.	metal	C	100 - 120W	RBS	----
14	Si	300	s.s.	e.b.	metal	C	100 - 120W	betain	----
19	^{39}K	10	C	e.b.	KI	Ta	30W	----	boat with a lid
19	K	10-20	C	e.b.	KCl	Ta	20W	----	with polarization
19	K	600 - 700	C	e.b.	KCl	Ta	20W	----	----
19	K	20	C	e.b.	K_2CO_3	Ta	20 a 40W	----	boat with a lid
19	K	80	C	e.b.	KI	Ta	20W	----	----
22	Ti	20	C	e.b.	TiO_2	Ta	80W	----	----
25	Mn	20-30	mylar+Al+Cu	J.h.	metal	W	5A	----	triple target Mn+Al+Cu
27	Co	30-200	C or Ta	e.b.	metal	C saturated with Co	40-60W	----	forms alloy with Ta, Mo e W
28	^{58}Ni	30-50	C	J.h.	metal	W	4A	----	----
28	^{60}Ni	30-50	C	J.h.	metal	W	4A	----	----

s.s. - self-supporting
e.b. - electron bombardment
J.h. - Joule heating

Table1 (2/3) Parameters used to fabricate nuclear targets.

Atomic Number	Element	Thickness $\mu g/cm^2$	Backing	Method	Chemical compound	Crucible(eb) Boat (jh)	Power (W) Current (A)	Parting Agent	Observations References
28	Ni	200-1000	s.s.	J.h.	metal	W	3-4A	RBS	----
28	Ni	1600	C 20$\mu g/cm^2$	J.h.	metal	W	3-4A	----	----
29	Cu	20-30	mylar+Al	J.h.	metal	W	4A	----	Mn+Al+Cu mylar
29	Cu	500	mylar	J.h.	metal	W	4-5A	----	----
29	Cu	500-1000	s.s.	J.h.	metal	W	4-5A	RBS	----
29	Cu	1000-2000	s.s.	J.h.	metal	W	4A	RBS	----
29	Cu	20-30	mylar	J.h.	CuS	Mo	5A	----	double target
30	Zn	30	C 10$\mu g/cm^2$	e.b.	ZnO	C	60-100W	betain	
30	Zn	30	C+Au	J.h.	metal	Ta		betain	glass funnel
30	^{66}Zn	30	C+Au	e.b.	ZnO	C	60-100W	----	C prep. with betain
32	Ge	30-50	s.s.	e.b.	metal	Ta	2A		28
38	^{88}Sr	40	C	J.h.	$^{88}SrNO_3$	W			
42	^{92}Mo	30	C	e.b.	metal	W	100 - 160W	----	27, 28
42	^{94}Mo	30	C	e.b.	metal	W	100 - 160W	----	28
42	^{96}Mo	30	C	e.b.	metal	W	100 - 160W	----	28
42	^{98}Mo	20-200	s.s.	e.b.	metal	W	100 - 180W	thick RBS	28
42	^{98}Mo	20	C	e.b.	metal	W	100 - 120W	RBS	28 glass slides
42	^{98}Mo	30	C	e.b.	metal	W	100 - 120W	RBS	28 C on frame
42	^{98}Mo	30	s.s.	e.b.	metal	W	100 - 120W	RBS	28
47	Ag	20	C 10$\mu g/cm^2$	e.b.	metal	W	15A	RBS	glass slide
47	Ag	400	mylar	J.h.	metal	Mo	2.0A	----	----
47	Ag	1mg/cm^2	s.s.	J.h.	metal	W	2.0A	RBS	----
47	Ag	20-30	mylar	J.h.	metal	W	2.0A		on target support
49	In	20	C	e.b.	metal	W	10 - 15W	----	----
49	In	24	C	e.b.	metal	Ta filament	10 - 15W	----	----

s.s. - self-supporting
e.b. - electron bombardment
J.h. - Joule heating

Revista Brasileira de Aplicações de Vácuo, Vol. 17, nº 1, 1998

Table1 (3/3) Parameters used to fabricate nuclear targets.

Atomic Number	Element	Thickness $\mu g/cm^2$	Backing	Method	Chemical compound	Crucible(eb) Boat (jh)	Power (W) Current (A)	Parting Agent	Observations References
49	In	20	C	J.h.	metal	W filament	----	----	----
50	Sn	30-50	C 10$\mu g/cm^2$	e.b.	SnO_2	Ta	40W	RBS ou betain	glass slide
50	Sn	280	Mylar	J.h.	metal	Ta	2 - 3A	----	on target support
50	Sn	150-600	Au 1.5mg/cm^2	e.b.	SnO_2	Ta	40W	----	----
50	^{124}Sn	500	Au	e.b.	metal	Ta	40 - 70W	----	----
50	^{120}Sn	400	Au 1mg/cm^2	e.b.	SnO_2	Ta	40 - 70W	----	Substr.refrig with N_2 cold finger
51	^{121}Sb	500	Au	e.b.	metal	Ta	20-30W	----	----
51	^{123}Sb	500	Au	e.b.	metal	Ta	20-30W	----	----
51	Sb	1000	Ni	e.b.	metal	Ta	20 - 30W	----	----
51	Sb	1000	Ni+Cu	e.b.	metal	Ta	20 - 30W	----	----
51	Sb	700 - 1200	Au 1 to 1.5mg/cm^2	e.b.	metal	Ta	20 - 30W	----	----
52	^{128}Te	700 - 1200	Au (1mg/cm^2)	e.b.	metal	Ta	40 - 70W	----	Au refrig support.
56	^{136}Ba	30 - 70	carbon	e.b.	BaF_2	Ta	30 - 60W	----	30
56	^{138}Ba	30 - 70	carbon	e.b.	$BaCO_3$	Ta	30 - 60W	----	30
65	Tb	500	Fe + Ag	e.b.	Tb_2O_3	Ta	80W	----	Au to avoid oxidation
67	Ho	1.3mg/cm^2	Fe + Ag	e.b.	Ho_2O_3	Ta	80W	----	reduction with Zr /Au to avoid oxidation
79	^{197}Au	300-1500	s.s.	J.h.	metal	W	2 - 3A	RBS and CsI	used as backing
79	Au	200-2000	s.s.	J.h.	metal	W	2 - 3A	RBS	used as backing
82	Pb	1000	mylar	J.h.	metal	Ta	2.5A	----	----
82	Pb	2000	Gd 1.8mg/cm^2	J.h.	metal	Ta	2.5A	----	----
82	^{208}Pb	13	Ni+Cu	J.h.	metal	Ta	2.0A	----	target support
82	^{208}Pb	50-140	C	J.h.	metal	Ta	2.0A	----	target support
82	^{208}Pb	5 - 30	C	J.h.	metal	W	2.0A	----	target support

s.s. - self-supporting
e.b. - electron bombardment
J.h. - Joule heating