Tailoring of targets for a tandem accelerator laboratory

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Abstract

The organization of a target laboratory serving the nuclear physics research at a tandem van de Graaff accelerator is described. Emphasis will be put on the layout of the laboratory and the mode of operation. The working force is about 40 h per week shared by two technical assistants, and they are supervised by a physicist who on the average spends about 1/3 of his time on target-related problems. The standard techniques employed will be presented briefly, but selected topics like heavy ion sputtering of actinides and the preparation of multilayer targets will be described in detail.

A main feature in the setup is a general target bank or library for the whole laboratory. It has been attempted to have a ready made target of as many isotopes as possible of most elements for any experimenter at all times. The basic framework of this system has worked successfully for about 10 years.

Introduction

Papers given at target development conferences mostly deal with specific techniques and preparations. Therefore, I have felt it important to describe a complete target laboratory where all these single operations are carried out. I also feel that it has a certain value to present a technique or preparation with some reference to the experiment for which it has been designed. This will therefore be the spirit of this talk.

The target laboratory of our institute came into operation during 1961 when our first tandem van de Graaff was ready for experiments. With a staff of a dozen Danish physicists and as many visiting physicists, the importance of a standardized and well organized target supply was realized. One of the physicists on the staff took the responsibility for development and daily care for all target related problems, and it was stressed that this person also ought to be active in the experiments at the accelerator.

In the years that have followed, we have learned to appreciate this decision, and it is probably also the reason why we have a very flexible and well organized target service today. With an active experimenter as leader, the understanding for different requirements concerning a target has been appreciated by those making it, and many unnecessary misunderstandings have been avoided.

The Target Laboratory

In the following, I will describe the main features of our target laboratory and how it is working.

One of the first things that was decided was to have one standard target frame, fig.1. It is made of 0.5 mm aluminium and has a window of 0.8 cm^2. The frames are numbered from 1 up to about 3000.

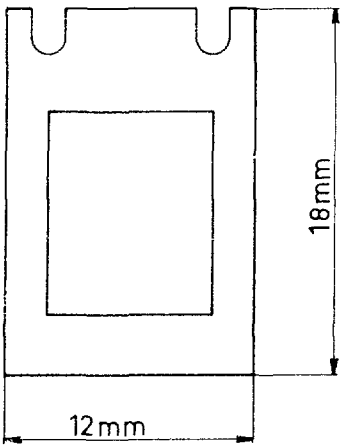

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Fig.1. Standard target frame.

All targets have their place in a target library in boxes, each one containing 200 numbers.

The keys to this library are a target file and a target catalog as indicated on the diagram, fig.2. The file contains all available isotopes of all elements with separate cards for each. On the card the index is by frame number. The following columns list method of preparation, backing, thickness and different comments like isotope sample (ORNL nr.), date of preparation etc.

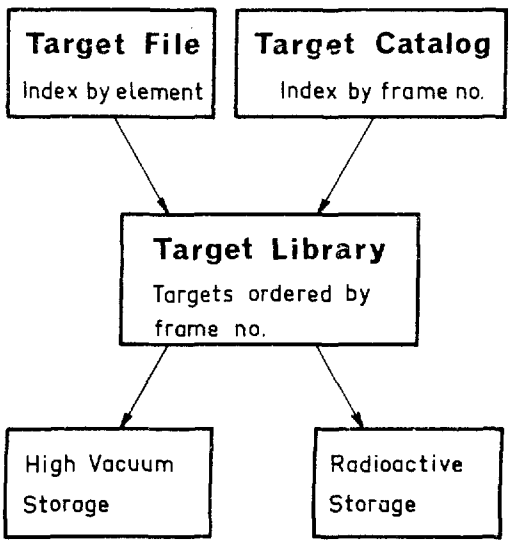

Fig.2. Organization of the target collection.

The target catalog is a listing of numbers from 1 to 3000 and by each number there are columns for the isotope, method of preparation, backing and so forth.

There are many targets that corrodize rapidly in air and cannot be stored in the target library. These targets are all stored at a pressure of $1x10^{-6}$ mm Hg in 3 glass jars, each one 30 cm wide and 12 cm high.

These targets are all replaced by dummies in the target library, indicating in which vacuum chamber they are stored.

Radioactive targets and actinide targets are stored separately in vacuum jars or dry boxes, but they are all registered in the general file and catalog and have their dummy in the target library.

The experimenter can now localize a target of a given isotope by the file and rapidly get all relevant information about it. If the user later on should forget what the target contains, he can by the number enter the target catalog and identify it.

After an experiment the targets are returned to the target laboratory whether it is damaged or not, and inspected by the personnel there before they are put back into storage. Targets that are damaged, are thrown out and erased in both the file and the catalog. The number, however, is used over again and in some cases even the frame. This might be a weak point in the procedure, but as long as the re-distribution of frames and numbers is restricted to those who scrap the damaged targets, we feel that the method is safe.

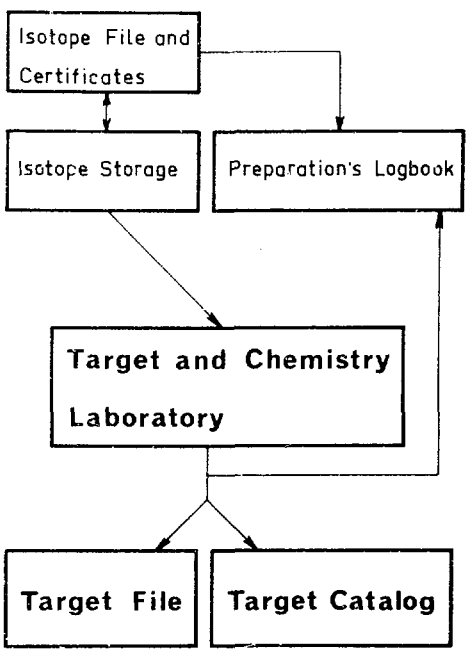

Fig.3. Target laboratory organization.

In fig.3, the connections between the input of isotope and the target library are displayed. The log book is particularly important because the experimenter can get an index to it in the target file and find out about details in the preparation that might be important for his results.

Everybody that has responsibility for a target laboratory knows that many physicists want to have their own targets, with their own name on the box, in their own drawer of their own office desk. One therefore would argue that a system as described above would break down because of long term loans and people having the targets, they were interested in, stored in their own rooms.

The thing to do is to convince all experimentalists about the advantage of a common pool of targets. He will himself have access to all targets available in the laboratory , and at the same time the target makers will be able to spend more time on developing new and rare targets.

In general, our system works well, but it is necessary from time to time to give people a reminder. Our motto is that we will do anything to promote physics, and with that in mind we think that the rigour of our system is justified.

The working force of the target laboratory consists of two technical assistants both working part time and together covering about 40 hours per week. They work under guidance of a physicist that devotes about 1/3 of his time to target related problems.

The target laboratory itself is physically divided in two, one for inactive targets and one for actinide targets and other radioactive targets. Both sections are equipped with vacuum evaporation units and heavy ion sputtering apparatus as general tools.

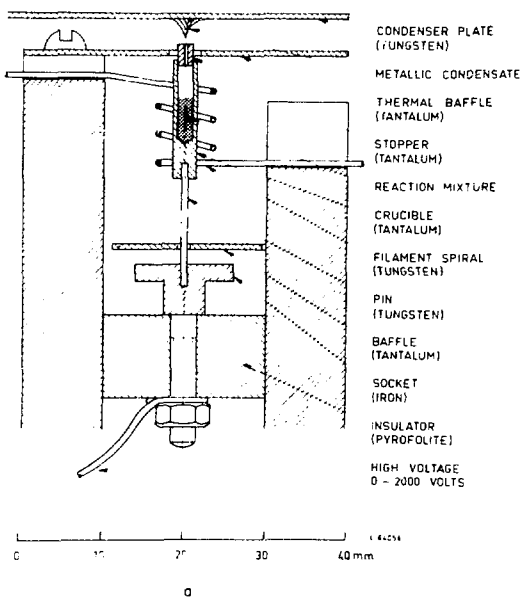

Fig.4. High efficiency electron bombardment assembly for T≦3000°C. Here set up for metallothermic reduction.

In addition to this, the inactive target laboratory has the following general equipment:

1. Pack roller for production of self supported metal targets.
2. Evaporation unit for carbon foils.
3. Argon glove-box with pack rolling equipment.
4. High frequency oven for reduction of oxides and melting.

The vacuum evaporation units are all built in the laboratory, ref.1. The one used for inactive work is shown in fig.4. It employs electron bombardment and can handle very small amounts with very high collection efficiency.

The radioactive evaporation unit is displayed in fig.5 and has many features in common with the inactive one, ref.2. What is special is that parts can easily be taken out and changed or stored away when they get contaminated. The whole thing is of course contained in a glove box shielded with absolute filters.

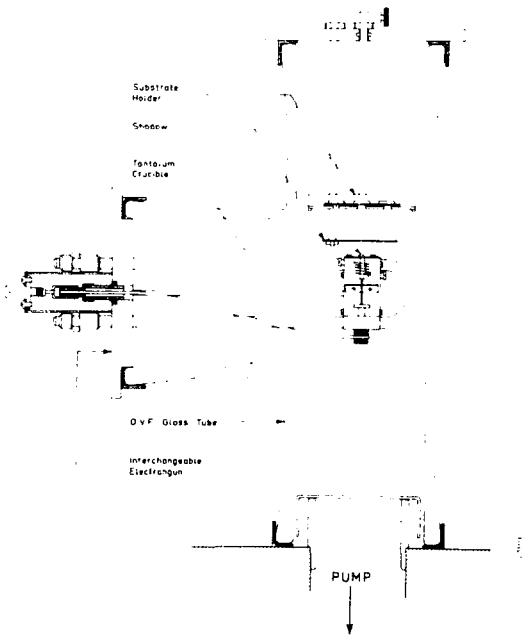

Fig.5. Electron bombardment unit for radioactive materials.

The heavy ion sputtering apparatus is shown in fig.6 and is identical for active and inactive work, ref.3. The radioactive sputter unit is contained in a glove box as shown in fig.7.

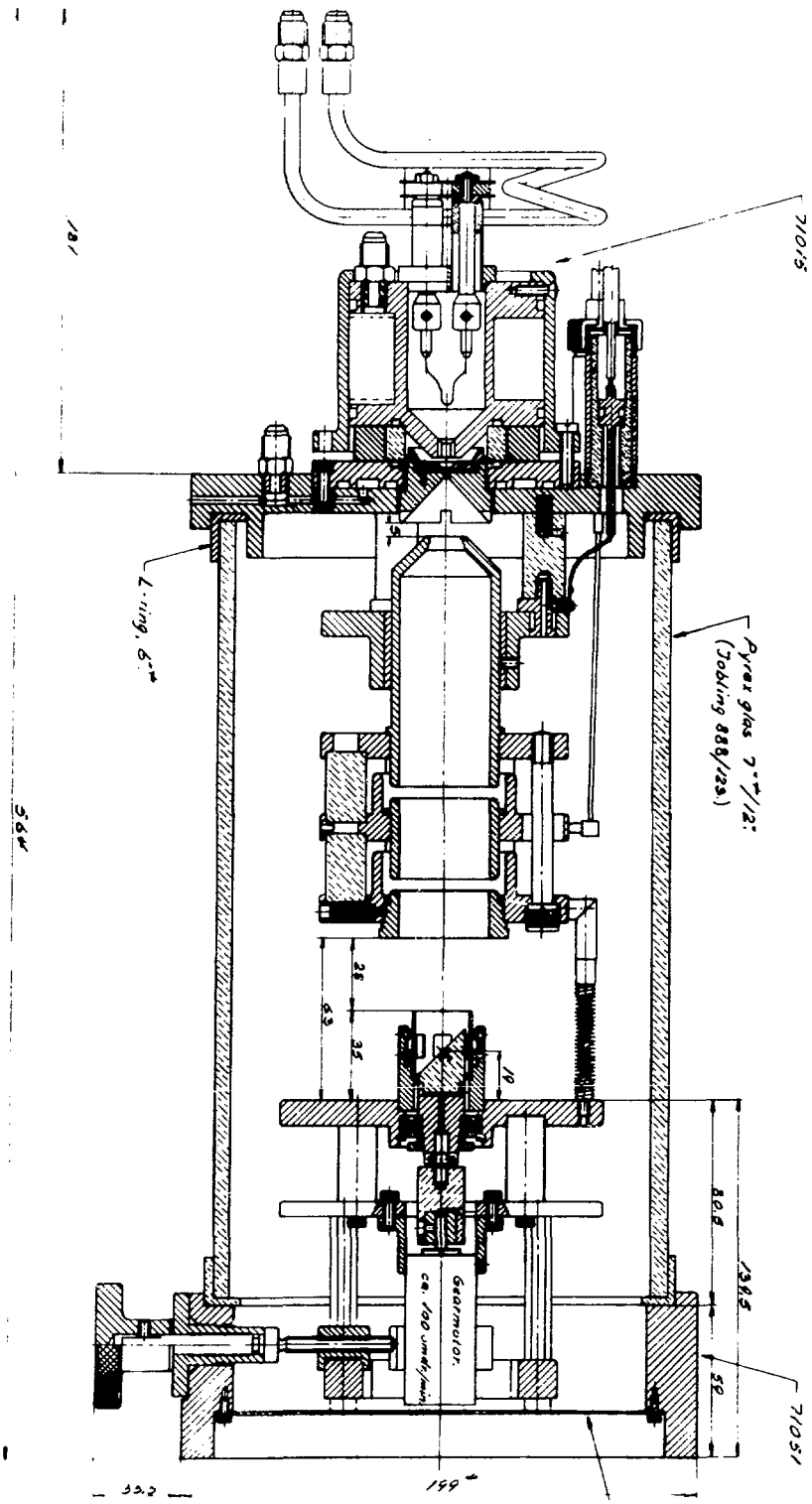

Fig.6. Heavy ion sputtering apparatus with high collection efficiency. The beam energy is 10 keV and a typical current about 1 mA. The beam stop can be rotated to obtain uniform targets.

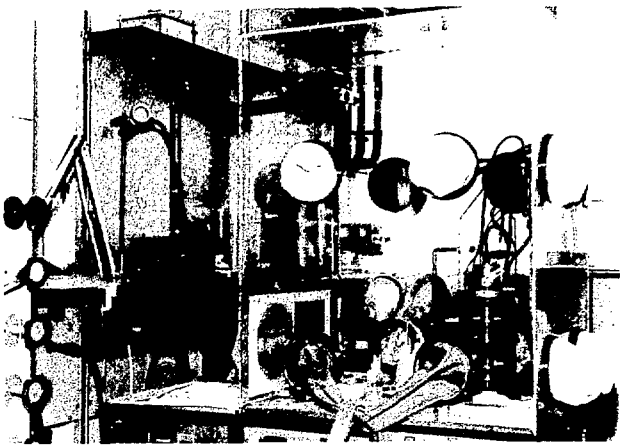

Fig.7. Glove-box with heavy ion sputtering equipment for actinide elements.

Preparation of Radioactive Targets

After this general description of our target laboratory I will carry on by mentioning three major achievements in more detail.

They all have to do with radioactive preparations although the first one concerns an almost stable isotope:

1. preparation of ^{41}Ca targets
2. actinide plunger targets
3. actinide, lead multilayer sandwich targets

1. ^{41}Ca Targets

The ^{41}Ca isotope with a half life of $8 \cdot 10^4$ years was produced in a Savannah River Reactor in the U.S.A. and mass separated at ORNL by Dr. L.O.Love and coworkers.

We obtained two batches of about 2 mg ^{41}Ca each and prepared 3 sets of targets from this material. Two preparations were carried out at the 1 mg scale and the remaining material in one.

The isotope was received in dilute nitric acid solution and the calcium was precipitated as the oxalate. After conversion to the oxide it was vacuum evaporated onto 30 $\mu g/cm^2$ carbon backings from a tantalum crucible.

The calcium oxide is reduced to the metal by the tantalum crucible and the deposits were shiny metallic films.

To collect as much of this unique material as possible, 18 carbon foils were mounted per evaporation. The result was about 10 targets with thicknesses about 100 $\mu g/cm^2$ and dozens of thinner targets down to a few micrograms per square centimeter.

With the 2 mg batch serveral targets of 200 to 300 $\mu g/cm^2$ were made. With thick targets it is important to avoid contact with the atmosphere because after oxidation reentry into vacuum would

cause peeling due to expansion of CO_2 and H_2O. We therefore transferred these targets to an argon glove-box without breaking the vacuum. There they were stored in an atmosphere containing less than 5 ppm of O_2 and H_2O and have been transferred to the experimental area in argon filled containers.

These targets have been involved in experiments not only in our own laboratory, but also on this continent, and all thinkable scattering and transfer reactions have been made with them.

They have been used in Munich, Groningen, Brookhaven, Rochester N.Y., ref.4, and Los Alamos to mention the most prominent ones.

2. Actinide Plunger Targets

The research programs dealing with fission require actinide targets, and we have solved the safety problems connected with those by establishing a special target laboratory for actinides. As indicated above, we use the same standard techniques as in the inactive laboratory, but all apparatus and desks for manipulation are enclosed in glove-boxes.

Actinide targets on carbon and metal backings can as a rule be quite successfully prepared by vacuum evaporation, ref.2. For some preparations, however, the large amount of heat from electron bombardment is hazardous. This inconvenience can however be overcome by the use of heavy ion sputtering.

The recoil distance method has quite successfully been applied to the study of fission isomers with half lives of a few nanoseconds as the lower limit. By application of plunger targets it has been possible to study isomers in the 10 picosecond range, and one has thereby been able to complete the systematics of fission isomer half lives in even-even plutonium nuclei.

To look for fission isomers is to look for a needle in a haystack because the probability of creating one is a million times less than the probability for prompt fission which takes place at the same time.

In the recoil distance method we take advantage of a geometrical separation of the delayed fission events from the prompt. The detection system works in such a way that only those nuclei which recoil out of the target and then decay by fission are detected as true delayed fissions. The uniform and very flat surface of a plunger gives a sharp time zero, and the recoil velocity determines the time scale.

In the reactions used most frequently the recoil velocity is about 0.6 nm/ns. When we now talk about isomers with half lives of 5 to 10 picoseconds, it means recoil lengths of about 3 μm. Therefore the limitations on the half life sensitivity are determined by the flatness of the target.

Fig.8 shows the suspended surface of a plunger target. The interference picture gives an idea of its flatness. An ideal object would give straight parallel interference fringes whereas deviations from straight lines indicate an unevenness in the target surface.

Deviations of the order of the distance between the fringes correspond to a difference in height of 0.3 μm. In the centre this particular target is planer than 0.5 μm.

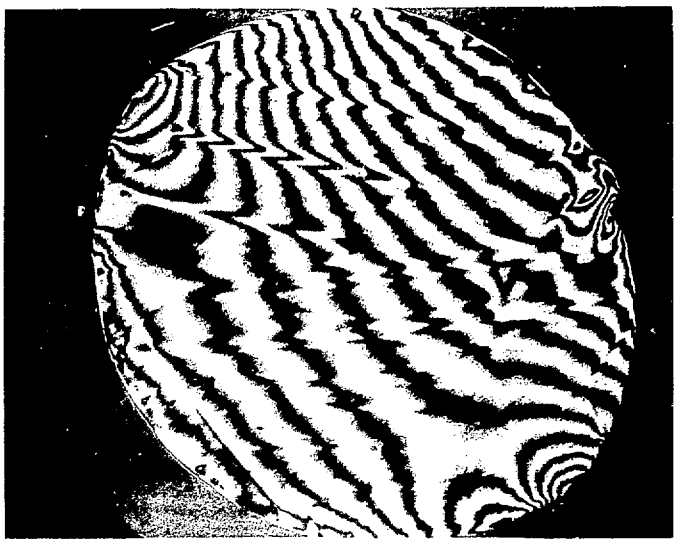

Fig.8. Interference picture of the suspended surface of a plunger target. For details see text.

With a recoil velocity of 0.6 mm/ns and this quality of plungers, it is the thickness of the deposited target material that puts the lower limit for half lives. Typical thicknesses are 30-60 $\mu g/cm^2$ of actinides.

A requirement for this special type of plunger is also that the target material is restricted to a central spot on the suspended membran and of the same size as the accelerator beam spot (diameter $\approx$ 1 mm), fig.9.

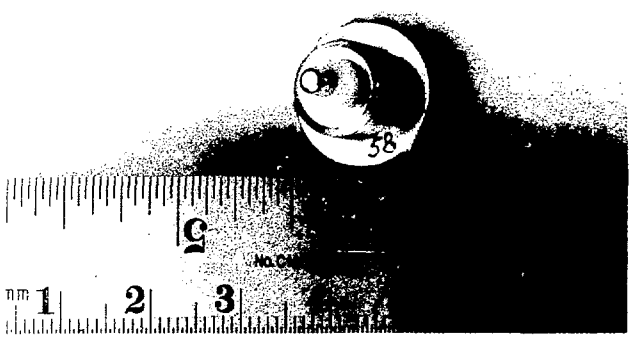

Fig.9. Plunger target with a ^{242}Pu deposit prepared by heavy ion sputtering. The plutonium isotope is restricted to the central area by a mask.

The material must therefore be deposited only after one has stretched the flat face of the plunger. Great care must be taken to shield off the rest of the plunger tube because any actinide material on the outside of the tube could fission by secondary neutrons coming from the beamspot just a few millimeters away. These fissions would create a background and could completely mask the real effect.

The plunger is prepared by stretching a piece of 1 mg/cm^2 Ni-foil over the outer tube by means of a teflon disc, fig.10, ref.5. As an extra precaution we sometimes apply a small amount of glue on the outside of the tube down at the base. Then the inner tube is carefully expanded and the resulting flat surface inspected by microscopy.

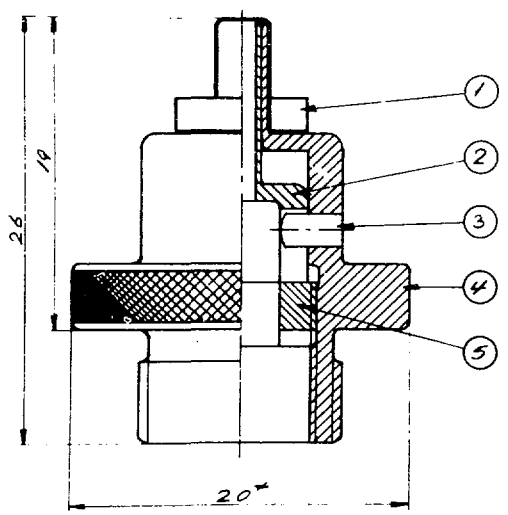

Fig.10. Plunger target holder with 2.3 mm outer tube diam. 1.Teflon ring. 2.Inner,expansion tube. 3.guiding pin. 4.Outer tube with alignment flange. 5.Nut for expansion of inner tube.

Thereafter a mask with a 1 mm diameter central hole is fitted on to the outer dimension of the plunger body and adjusted under microscope until it is less than a tenth of a millimeter from the suspended membran. The plunger is then ready for deposition of the actinide isotope.

The isotopes are deposited by argon sputtering of oxides or metals with the plunger flat surface 25-30 mm away from the sputtering centre. To obtain a 50 µg/cm^2 target of plutonium in this collection geometry we have to apply 0.5 mA of beam for about 50 minutes or on integrated current of about 1500 millicoulombs.

During an experiment the beam might heat up the target foil so much that wrinkles may appear. It is therefore advisable to have a spring mounted between the expansion screw and the inner cylinder of the plunger to allow for expansion.

We also insert a beam collimator just behind the expansion screw to stop any stray beam at that point and take excess heat away.

We now have experience in preparing plunger targets of uranium, neptunium, plutonium and americium. The amounts of isotope needed for a preparation is of the order 5 mg. This does not mean that so much material is consumed to make a target of the type described above. Five milligrams is just a convenient amount of material to work with and is sufficient for several preparations. We have for example sputtered targets of ^{244}Pu from about one milligram of isotope.

We have also carried the plunger technique one step further by going to sloping surfaces. The reason is that one has wanted to study angular correlations of fission fragments from picosecond fission isomers. The traditional plunger gives the possibility of measuring at 90°, but we have produced plungers that have their suspended surfaces 20° to the beam axis.

3. Actinide Sandwich Targets

The other type of sputtered actinide targets we have developed recently is multilayer sandwich targets. A problem in measuring angular correlations and perturbed angular correlations of fission fragments is the attenuation of the correlation by extranuclear fields. These fields originate partly from the crystal structure of the medium and partly from the creation of vacancies in the atomic shells as a result of radiations. The extranuclear fields can attenuate an angular correlation almost to isotropy and the target makers' problem has therefore been to find a medium which reduces the attenuation to a minimum.

It has been observed that γ-ray angular correlations are very well preserved when polonium nuclei recoil into a lead lattice, ref.6. We have therefore adopted lead as stopping material, and we let the recoiling reaction products stop in lead.

Since the recoil energy is low in these experiments, one must keep the thickness of actinide down to about 20 $\mu g/cm^2$. Otherwise the recoil would stop in the actinide itself and probably be subject to strong extranuclear fields.

At the same time, the cross section for producing the isomers is so low that a 20 $\mu g/cm^2$ layer of actinide with a lead stopping layer on top would be unacceptable. We have therefore developed a target consisting of 40 layers of actinide interspaced by 40 layers of lead.

The backing is a 2 mg/cm^2 copper foil and the actinide isotope and the lead are deposited by heavy ion sputtering. We have for example ^{239}Pu in one cavity of the beam stop and lead in another cavity 5-10 mm away. The target frames with the copper backings are mounted about 20 mm away in a cylindrical geometry and are rotated around the beam stop by an electro motor.

The beam of argon ions is now focused onto the actinide to a 1 mm^2 spot and a layer of 20 $\mu g/cm^2$ of ^{239}Pu is very evenly deposited on the rotating backings. We then remotely move the whole beam-stop with substrates until the lead coincides with the beam axis, and we sputter 70 $\mu g/cm^2$ of lead on top of the plutonium.

After this we go back to plutonium and the whole sequence is repeated 40 times. The sputtering is controlled by a beam integrator which can be preset to a certain number of millicoulombs and reproduction is very simple. The number of millicoulomb that gives a certain thickness is determined in a short test sputtering. The yield of actinide can be determined by α-counting of its natural radioactivity and the lead yield by elastic scattering of α-particles at the tandem accelerator.

To sputter a 20 $\mu g/cm^2$ layer of ^{235}U from the metal takes 15 minutes, and the 70$\mu g/cm^2$ lead layer 5 minutes. Effectively, one would therefore have to spend 13 hours on this type of preparation. We make 5 targets at a time in this way so they each represent almost 3 hours of work. On the other hand, the result is such a major break through in the study of fission isomers and intermediate states in fission that we feel the work is justified.

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