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NEW PRODUCTION SYSTEMS AT ISOLDE

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Abstract

New target systems for the ISOLDE on-line mass separator facility are presented. Targets of carbides, metal/graphite mixtures, foils of refractory metals, molten metals and oxides have been tested. Beams of high intensity of neutron-rich isotopes of a large number of elements are obtained from a uranium carbide target with a hot plasma-discharge ion-source. A target of ZrO_2 has been shown to provide high intensity beams of neutron deficient isotopes of Mn, Cu, Zn, Ga, Ge, As, Se, Br, Kr and Rb, while a SiC target with a hot plasma ion-source gives intense beams of radioactive isotopes of a number of light elements. All these systems are rather chemically unselective. Chemically selective performance has been obtained for several systems, i.e.; The production of neutron-deficient Au from ($^3\text{He}, \text{pxn}$) reactions on a Pt/graphite target with a hot plasma ion-source; The production of neutron-deficient Lu as LuF^+ and Hf as HfF_3^+ from a Ta-foil target with a hot plasma ion-source under CF_4 addition; The production of neutron-deficient Sr as SrF^+ and Y as YF_2^+ from a Nb-foil target with a W surface ionizer under CF_4 addition; The production of neutron deficient Se as COSe^+ from a ZrO_2 target with a hot plasma ion-source under O_2 addition; The production of radioactive F from a SiC target with a hot plasma ion-source operating in Al vapour.

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1. Introduction.

The development of rapid, efficient and chemically selective targets is an important part of the work at the ISOLDE on-line mass-separator facility. For the elements with the most simple chemistry, e.g. the alkali metals and the noble gases, targets fulfilling all these three requirements have to a large extent been available for a long time, but for most elements, at least one of the requirements is usually difficult to meet.

The previous target work at ISOLDE has been mainly concentrated on the development of new target materials and the construction of improved ion-source systems, and is reviewed in refs. [1-3]. Some target materials which have not been used before will also be presented here, but in this article, we focus less on the traditional development of materials and ion-sources and more on the refinements of partly already existing systems. It will be shown that simple chemical techniques can accomplish substantially improved conditions for a number of product elements.

The details of the lay-out of the ISOLDE target and ion-source systems, as well as the general features of the ISOLDE facility when it was situated at the CERN synchro-cyclotron (SC) can be found in refs. [1-4]. At present, the SC has been closed down and the facility has moved to the proton synchrotron (PS) booster. The details of the new facility have been described by Kugler in these proceedings [5].

2. The ISOLDE targets.

The CERN synchro-cyclotron delivered up to $3\ \mu\text{A}$ of 600 MeV protons or 910 MeV ^3He , and at the PS booster, the proton energy will be 1 GeV. Due to the high penetrability of these particles, thick targets containing large amounts of target material can be used. The production yields at maximum are up to $10^{10} - 10^{11}\ \text{s}^{-1}\mu\text{A}^{-1}$. The targets are kept in a tubular Ta container, normally of 20 cm length and 1.9 cm diameter (design: see ref. [2]). The heating is supplied partly by the incident particle beam, and the target cylinder can also be heated resistively by means of a high current passing through it.

2.1 Target materials.

The target materials must fulfill a number of conditions in order to be useful for ISOLDE application. In addition to the evident requirement of a high formation cross section for the nuclides of interest, it must also have an acceptable vapour pressure at the running temperature, ability to provide a rapid and continuous release of the desired product element, and a stable and non-corrosive behavior towards the container material. As illustrated schematically in fig. 1, there are several sources for loss at the different steps of the mass-transfer process a radioactive atom undergoes from the formation in target to the ionization in the ion source. Most important is normally the decay loss due to a slow release-rate from the target.

Traditionally, the release rate has simply been optimized by heating the target to a temperature at which the desired nuclear reaction product leaves the target material sufficiently fast, and tests of possible target materials with respect to release-rate have always constituted an important part of the target development work at ISOLDE [6,7]. The most commonly used target materials are molten metals or powders of carbides, oxides or refractory metals. The refractory metals are also frequently used in the form of foils, in order to minimize the total surface in the target and thereby decrease the surface delay. In

the present work, we present results from a new type of target material, i.e. mixtures of graphite powder and metals which do not form thermostable carbides.

Several workers [8-10] have shown that the surface desorption and not the in-grain diffusion is the main source of delay for many elements. Experiments with addition of reactive gases [11-13] have shown that a slow surface desorption may be improved through the addition of reactive gases, converting the radioactive atom to a volatile chemical form. In particular, carbon tetrafluoride (CF_4) has been shown to enhance the release rate of group 3 and group 4 elements. In this paper, we demonstrate the application of this method to several production systems.

2.2 Chemical selectivity

Due to the complexity of high energy nuclear reactions, high production yields alone are not sufficient. The yields at maximum are seldom interesting. Very often, the nuclide sought for has a yield several orders of magnitude below the maximum. Thus, the mass separated beams must be as chemically pure as possible. Ideally, they should only contain one single element. If a target system produces everything with high efficiency, the observation of the interesting and exotic nuclides will be hampered by the presence of isobars closer to stability. Therefore, unselective target systems are often only useful to experiments utilizing element-selective detection-methods, e.g. laser spectroscopy.

The methods commonly used to obtain chemically selective production are well described [1-3]. A trivial type of chemically selective performance occurs from the simple fact that many elements never leave the target material at all. Positive and negative surface ionization have been applied to produce chemically pure beams for a long time, in particular for the alkali metals and the halogens Cl, Br and I.

Another traditional method is the use of a cooled transfer-line to inhibit the transport of less volatile elements from the target to the ion source. This technique has been applied to obtain chemically pure conditions for noble gases and a few volatile metals e.g. Zn, Cd and Hg.

The methods described above are only applicable to a limited number of elements. Therefore, more sophisticated methods utilizing for example the possibility of stepwise laser ionization [14] are currently under development. Another possibility is to use high resolution separators to separate isobars [15], a method recently used at ISOLDE-3 to investigate ^{37}Ca free from disturbing amounts of the much more abundant isobar ^{37}K .

2.2 Molecular side-bands

Molecular side-bands are well-known in on-line mass separators, mostly as a source for distressing contamination. In some cases, erroneous assignments of molecular side-bands have even found their way into literature. However, it has been shown that a controlled and reproducible production of molecular ions is possible, and that they can be used to obtain chemically selective performance [11-13]. In particular, fluoride side-bands obtained through CF_4 addition have been found useful.

In the present paper, we show several examples on how the separation of molecular side-bands recently has been used in a positive way to provide high intensity, chemically pure ion-beams at the ISOLDE on-line mass separators for a variety of elements.

3. New ISOLDE production methods.

The ISOLDE mass separators were recently equipped with simple gas-addition systems, enabling the easy, steady and controlled supply of different gases into the target system. The handling of the gases is performed in a reservoir positioned outside the highly radioactive separator front-end. A tube leads the gas from the reservoir into the target unit. Each target unit can be equipped with a calibrated leak, through which the gas is admitted to the target. Different gases may be easily mixed in the reservoir, and turning the gas-stream on and off is an operation which only takes a few minutes. The type of gas in the reservoir can also be rapidly changed. The gas pressure inside the target is regulated simply by varying the external pressure in the reservoir. A detailed description of the gas-addition system is given in ref. [13].

In the following, descriptions of the most recently developed production systems at ISOLDE are given, as well as curves showing the most important yields from the systems. The lines drawn in the curves are only to guide the eye.

3.1 Neutron deficient Au from a platinum/graphite target.

Neutron deficient isotopes of Au can be produced from a target consisting of a mixture of Pt powder and graphite powder. The details of the system are described in ref. [16]. Unlike most metals, Pt does not form a thermostable carbide in the presence of excess graphite [17]. At the running temperature, 1800 - 1900 °C, the target is more like a mixture of graphite powder soaked with molten platinum.

When irradiated with ^3He , this system produces neutron-deficient isotopes of Au with good yields (fig. 2). The chemical selectivity is also good. Large amounts of radioactive isotopes of the elements from Hf to Pt are produced in the target, but all these elements are refractory, and never leave the target material. Some radioactive Hg is produced from ($^3\text{He}, \text{xn}$) reactions, but the cross-section for this reaction is 1-2 orders of magnitude less than the cross-sections for formation of the Au isobars. Unfortunately, Au desorbs slowly from Ta surfaces [18], resulting in a delay of several minutes. This problem may be solved by a recently tested all-graphite ion-source.

3.2 Neutron deficient Cd from a tin/graphite target.

Neutron deficient Cd isotopes have traditionally been produced from a target of molten Sn, but due to long delay in the target, the conditions have not been satisfactory for the Cd isotopes with half-lives of some seconds. As Sn does not form thermostable carbides, a target was prepared by mixing powders of SnO and graphite. By heating, the SnO is reduced to metallic Sn, resulting in a Sn/graphite target similar to the Pt/graphite target described above. The transfer-line is cooled to 300 °C in order to inhibit the transfer of less refractory reaction products and Sn vapour to the ion source.

The yields of neutron deficient Cd from this target under irradiation with 910 MeV ^3He are given in fig. 3. Compared to a molten Sn target, the yields are the same for the short-lived Cd isotopes and a factor of 5-10 lower for the long-lived ones, because the Sn/graphite target has a shorter delay, but contains less target material than a molten Sn target.

3.3 UC target with hot plasma ion-source.

Uranium carbide targets have been used at ISOLDE for a long time, and the combination of uranium carbide target and hot surface ionizer is the most commonly used system at ISOLDE. When a uranium carbide target is combined with a hot plasma-discharge ion-source, a multitude of product elements are observed.

Some of the product elements may be produced with good chemical selectivity from specially dedicated ion-sources [1-3], and are not discussed in detail here. Intense, but unselective beams of several other elements are obtained with a plasma discharge ion-source, and may be useful for experiments requiring high intensities at maximum yield, or to experiments using element selective detection methods. A similar spectrum of product elements is obtained from the UC target at the fission product separator OSIRIS [19].

No detailed investigations of delay in the target were performed. The following product elements seem to leave the target rapidly, and radioactive beams of them are observed with high intensities: He, Li, Ne, Na, Mg, Al, Cl, Ar, K, Ca, Mn, Cu, Zn, Ga, Ge, As, Br, Kr, Rb, Sr, Ag, Cd, In, Sn, Sb, Te, I, Xe, Cs, Ba, Hg, Tl, Pb, Bi, Po, At, Rn, Fr, Ra. Up to Ba, the maximum yields occur for neutron-rich nuclides, arising from fission, while for the heavy elements produced, i.e. elements above gold, the production is due to spallation processes resulting in more neutron deficient products and maximum yields occurring close to stability.

Selected yield-curves from the UC target with hot plasma ion-source are given in figs. 4-8. In fig. 4, the yields of Mg and Al are given. The Mn yields are given in fig. 5, and fig. 6 shows the yields of the elements Cu, Zn, Ga, Ge, As and Se. Fig. 7 shows the yields obtained for isotopes of Ag, Cd, In, Sn, Sb and Te, while the yields measured in the spallation region, i.e. for the elements Hg, Tl, Pb, Bi, Po and At are shown in fig. 8.

Refractory elements and elements forming refractory carbides are very slowly released from this type of target. Results from the OSIRIS mass separator [11] as well as off-line release tests [6] had shown that the addition of CF_4 could improve the release properties of the rare earth elements considerably, and lead to the formation of molecular ions. CF_4 was therefore administered to the target. However, the gas addition did not significantly improve the release rate. Mono- and difluoride ions e.g. BaF^+ , LaF^+ and LaF_2^+ were observed, but the yields did not improve. Actinium was observed for the first time at ISOLDE, as AcF^+ , but with long delay and with low yield. The CF_4 addition did not lead to any useful new ion-beams.

Considering previous results, the failure of the CF_4 addition to the UC target was not expected, and the reasons for it are not clear. Because previous results clearly show improved conditions for the rare earth elements, the work on this system will continue.

3.4 Nb-foil target with W surface ionizer under CF_4 addition

Targets of Nb foil have been used previously in various systems, but have not been found useful for production of neutron deficient Sr and Y so far.

When a Nb foil target equipped with a W surface ionizer is operated in an atmosphere of $5 \cdot 10^{-4}$ torr of CF_4 , its behavior changes drastically. At these conditions, high intensity beams of neutron deficient Sr and Y are produced, mainly as SrF^+ , YF^+ , and YF_2^+ . For neutron deficient isotopes of Sr, the sources are in practice chemically pure. Fluoride side-bands of Rb isotopes are not seen, and the presence of YF^+ does not disturb, because Y is further from stability than Sr. At the difluoride side-band, pure sources of Y as YF_2^+ are observed, and the conditions are thus close to ideal for this element.

The pure conditions obtained for Sr and Y through the separation of molecular ions have already enabled the identification of the new nuclei ^{76}Sr and ^{79}Y [20], and further experiments in this region are planned.

The production yields of SrF^+ and YF_2^+ from the Nb foil target in a CF_4 atmosphere are given in figs. 9 and 10.

3.5 Ta foil target with hot plasma ion-source under CF₄ addition.

Targets of Ta foil have been extensively used at ISOLDE for several years. A target of this type was equipped with a hot plasma-discharge ion-source and operated under CF₄ atmosphere.

To optimize the conditions for production of molecular ions is more complicated with a plasma-discharge ion-source than with a surface ionizer. Normally, it is advantageous to keep the anode voltage of such an ion-source high, but not if the production of molecular ions is to be enhanced. The ISOLDE hot plasma-discharge ion-source normally runs with an anode voltage of 150-200 V. At this voltage, we only observed molecular ions from Lu, which showed a strong tendency to form LuF⁺ and LuF₂⁺ beams. For reasons presently not understood, molecular ions of the other rare earth elements were not observed.

The production of Lu as LuF⁺ at the normal anode voltage is chemically selective, and the yields are given in fig. 11.

When the anode voltage was lowered to 110 V, the side-band yields increased drastically. Strong molecular side-bands from the other rare earth elements were now found. For instance, the stable ⁸⁹YF₂⁺ from a slight yttrium contamination increased by a factor of 5. More important, a strong molecular side-band of radioactive Hf in the form of HfF₃⁺ ions was found. There are no disturbing activities present at these masses, and the side-band therefore produces chemically pure sources of neutron deficient isotopes of Hf. The production yields of Hf as HfF₃⁺-ions are given in fig. 12.

3.6 Ti foil target with W surface ionizer under CF₄ addition.

When a target of Ti foil equipped with a W surface ionizer is operated under a CF₄ atmosphere, molecular ion beams of radioactive isotopes of Ca and Sc are observed. However, the intensity of the ScF⁺ and the CaF⁺ beam only amount to 10 % and 2-3 % of the respective beams of the corresponding elementary ions. For reasons not understood, we do not observe any ScF₂⁺ side-band from this system.

The yields of radioactive isotopes of Ca and Sc from this target are given in the figs. 13 and 14. From the difference between yields of short-lived and long-lived Sc isotopes, it is seen that the delay of this element in the target was of the order of several hours. An inspection of the material after the run showed that the target material had been molten.

3.7 Molten La target with W surface ionizer under CF₄ addition.

A useful BaF⁺ side-band was reported from the ISOLDE group in 1975, from a test of a molten La target [21]. The source of fluorine was then a contamination of the target material. With a controlled CF₄ leak providing a pressure of about 5•10⁻⁴ torr in the target, a stable BaF⁺ side-band amounting to about 8 % of the corresponding Ba⁺ intensities was obtained. A detailed measurement of Ba yields with this system was not performed.

3.8 ZrO₂ target with hot plasma ion-source under O₂ addition.

In general, oxide targets have a higher sintering rate than targets of carbides and pure metals, resulting in inferior release properties. However, an oxidizing environment may be advantageous for the production of e.g. group 5a and 6a elements. The most refractory oxides available are ZrO₂, HfO₂, and ThO₂. The two former are commercially available in the form of long, needle-like fibers, which may be manufactured into a cloth or a felt-like material, normally used for electrical insulation (Leico Industries, New York). This material turned out to be very suitable in targets, and sinters much more slowly than a pure powder.

From the pure ZrO_2 target equipped with a hot plasma-discharge ion-source, we obtain an unselective production of neutron deficient isotopes of the elements Mn, Cu, Zn, Ga, Ge, As and Se, as well as Br, Kr and Rb, which are more efficiently produced from metal targets. At maximum, the yields of all these elements are of the order of 10^8 at/s μA , and similar to the yields obtained from a Nb foil target with the same ion-source [22].

In order to investigate the possibility of molecular ion formation, an oxygen leak was introduced. When the target was operated under a pressure of $5 \cdot 10^{-4}$ torr of O_2 , a chemically selective production of neutron deficient Se, because the molecular ion COSe^+ , a carbon dioxide analog, was observed. The source of the carbon is a construction detail in the hot plasma ion-source. The mechanism for its formation is not known. No other molecular ions were seen. A search for COS^+ was inconclusive. The chemically pure production made it possible to identify the two new Se isotopes $^{67,68}\text{Se}$, and to perform spectroscopical investigations of them [23]. The gas addition seemed to have no influence on the yields of the other elements produced from this target system, and there were apparently no changes of the release properties. The yields of the other elements were not affected by the oxygen leak.

We did not look for the COSe^+ side-band before the gas addition, and it is not clear if it was there even before oxygen gas was administered to the target. At the end of the target test, the side-band showed no tendency to decrease for more than an hour after the leak was closed, but this behavior may be due to a "memory"-effect from gas adsorbed to surfaces in the target.

The yields of Mn, Cu, Zn, Ga, As and Se without gas addition are given in fig. 15, and the yields of Se in the form of COSe^+ , are given in fig. 16.

3.9 The silicon carbide target with hot plasma ion-source under Al vapour.

One of the most interesting refractory materials available at low masses is silicon carbide, and a target of this material was prepared and equipped with a hot plasma-discharge ion-source. The production yields of radioactive isotopes of Mg, Na and Ne from this target are shown in fig. 17.

It turned out that the target material was heavily contaminated with stable aluminium, so no production of radioactive Al was observed. However, it turned out that the Al vapour reacted with radioactive fluorine to form the molecular side-band AlF^+ . By means of this side-band, chemically pure sources of radioactive fluorine are obtained.

The yields of radioactive F isotopes obtained as AlF^+ ions are shown in fig. 18. The target material limits the possibility for F production up to ^{23}F . It is likely that a more efficient and still chemically selective production of neutron-rich F isotopes can be obtained by another target system, e.g. by supplying Lu vapour to a Pt/graphite target.

3.10 The thorium carbide target with hot plasma ion-source under Al vapour.

In order to facilitate the chemically selective production of At in a similar way, a ThC target was equipped with a mass-marker oven containing Al, so that Al vapour could be administered to the target in a controlled way. The temperature of the mass-marker oven was adjusted to provide a stable Al^+ beam similar to the one observed from contamination in the SiC target. The molecular ion AlAt^+ was not observed, although about 1 % of the radioactive iodine occurred as AlI^+ ions. Consequently, aluminium addition method is not suitable for production of chemically pure sources of At.

In no cases, the addition of a reactive gas seemed to have any negative influence on the performance of the ion-source or the life-time of the target units.

4. DISCUSSION.

The results presented above illustrate that the controlled addition of different reactive gases may be a very useful tool to obtain chemically selective performance of several target systems. By choosing the right gas, beams of complete chemical purity may be obtained in some favourable cases. Sometimes, but not always, the gas also improves the release properties. For some refractory elements, e.g. Hf, the presence of a reactive gas is imperative, because the very refractory element must be converted to a volatile chemical form in order to leave the target material at all.

This present work has shown how the separation of molecular ions can provide chemically pure or almost pure high-intensity beams for the elements F, Se, Sr, Y, Ba, Lu and Hf. Apart from the possibilities that may arise from selective laser ionization in the future, it is hard to see any alternative methods for obtaining chemically pure sources of these elements.

It is important that the gas can be administered to the target in a controlled and reproducible way, and the calibrated leaks combined with gas reservoirs operating close to atmospheric pressure have turned out as a very satisfactory way to obtain stable conditions. However, it is also possible to add a metal vapour by means of a controlled heating of a mass-marker oven.

Although a number of useful and reproducible molecular ion methods now are available, there is a need for extensive and systematic work to clarify the optimum conditions for molecular ion formation. There are still many open questions. The reasons for the failure of the CF_4 addition to carbide targets are not clear, and the optimum conditions with respect to important system parameters e.g. the type of reactive gas and its partial pressure, target temperature, ion-source temperature and anode voltage must be determined through systematic off-line experiments. Work in this direction is presently being performed.

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REFERENCES

- [1]. T.Bjørnstad, E.Hagebø, P.Hoff, O.C.Jonsson, E.Kugler, H.L.Ravn, S.Sundell and B.Vosicki, *Physica Scripta* **34** (1986) 578
- [2]. T.Bjørnstad, E.Hagebø, P.Hoff, O.C.Jonsson, E.Kugler, H.L.Ravn, S.Sundell and B.Vosicki, *Nucl.Instr.Meth.* **B26** (1987) 174
- [3]. H.L.Ravn, T.Bjørnstad, P.Hoff, O.C.Jonsson, E.Kugler, S.Sundell and B.Vosicki, *Nucl.Instr.Meth* **B26** (1987) 183
- [4]. B.W.Allardyce and H.L.Ravn, *Nucl.Instr.Meth.* **B26** (1987) 112
- [5]. E.Kugler et al., these proceedings
- [6]. P.Hoff, O.C.Jonsson, E.Kugler and H.L.Ravn, *Nucl.Instr.Meth.* **221** (1984) 313
- [7]. L.C.Carraz, I.R.Haldorsen, H.L.Ravn, M.Skarestad and L.Westgaard, *Nucl.Instr.Meth.* **148** (1978) 217
- [8]. G.J.Beyer, W.D.Fromm and A.F.Novgorodov, Raport der Akademie der Wissenschaften der DDR, Zentralinstitut für Kernforschung, Rossendorf, Dresden, DDR, ZfK-report 309 (1976)
- [9]. G.J.Beyer and A.F.Novgorodov, Raport der Akademie der Wissenschaften der DDR, Zentralinstitut für Kernforschung, Rossendorf, Dresden, DDR, ZfK-report 305 (1976)
- [10]. G.Rudstam, P.Aagaard and H.U.Zwicky, The Studsvik Science Research Laboratory, Studsvik, Nyköping, Sweden, Research Report NFL-42 (1985), p.24
- [11]. P.Hoff, L.Jacobsson, B.Johansson, P.Aagaard, G.Rudstam and H.-U.Zwicky, *Nucl.Instr.Meth* **172** (1980) 413
- [12]. J.C.Putaux, J.Obert, L.Kotfila, B.Roussiere, J.Sauvage-Letessier, C.F.Liang, A.Peghaire, P.Paris and J.Giroux, *Nucl.Instr.Meth.* **186** (1981) 321
- [13]. R.Eder, H.Grawe, E.Hagebø, P.Hoff, E.Kugler, H.L.Ravn and K.Steffensen, submitted to *Nucl.Instr.Meth.*
- [14]. V.Mishin et al., these proceedings
- [15]. M.Przewloka et al., these proceedings
- [16]. H.Andreasen, R.Eder, H.Grawe, H.Haas, E.Hagebø, P.Hoff, H.L.Ravn, K.Steffensen and S.Sundell, *Nucl.Instr.Meth.* (in print)
- [17]. T.B.Massalski, ed., "Binary Alloy Phase Diagrams" (Am.Soc. for Metals, Metals Park, Ohio, 1986), p.583

- [18]. H.Rossbach and B.Eichler, Raport der Akademie der Wissenschaften der DDR, Zentralinstitut für Kernforschung, Rossendorf, Dresden, DDR, ZfK-report 527 (1984)
- [19]. L.Jacobsson, B.Fogelberg, B.Ekström and G.Rudstam, Nucl.Instr.Meth **B26** (1987) 223
- [20]. H.Grawe, P.Hoff, J.P.Omtvedt, K.Steffensen, R.Eder, H.Haas and H.L.Ravn to be published
- [21]. H.L.Ravn, S.Sundell and L.Westgaard, Nucl.Instr.Meth. **123** (1975) 131
- [22]. E.Hagebø, P.Hoff, O.C.Jonsson, E.Kugler, H.L.Ravn, S.Sundell and B.Vosicki, The Analyst **114** (1989) 307
- [23]. P.Baumann, M.Bounajma, A.Huck, G.Klotz, A.Knipper, G.Walter, G.Marguier, H.L.Ravn, C.Richard-Serre, E.Hagebø, P.Hoff and K.Steffensen, Proc. Workshop "Nuclear Structure of Light Nuclei far from Stability, Experiment and Theory", Obernai, France, 1989, G.Klotz, ed., p.43

Figure captions.

Fig. 1

The mass-transfer process between target and ion-beam.

Fig. 2

Production yields of Hg and Au isotopes from a Pt/graphite target (7.9 g Pt/cm²) at 1900 °C, irradiated with 1 particle μ A ³He beam.

Fig. 3

Production yields of Cd isotopes from a Sn/graphite target (20 g Sn/cm²) at 1000 °C, irradiated with 1 particle μ A ³He beam.

Fig. 4

Production yields of Ne, Na, Mg and Al isotopes from a uranium carbide target (9.7 g U/cm²) at 1950 °C, equipped with a hot plasma-discharge ion-source, irradiated with 1 μ A 600 MeV protons.

Fig. 5

Production yields of Mn isotopes from a uranium carbide target (9.7 g U/cm²) at 1950 °C, equipped with a hot plasma-discharge ion-source, irradiated with 1 μ A 600 MeV protons.

Fig. 6

Production yields of isotopes of Cu, Zn, Ga, Ge and As from a uranium carbide target (9.7 g U/cm²) at 1950 °C, equipped with a hot plasma-discharge ion-source, irradiated with 1 μ A 600 MeV protons.

Fig. 7

Production yields of isotopes of Ag, Cd, In, Sn, Sb and I from a uranium carbide target (9.7 g U/cm²) at 1950 °C, equipped with a hot plasma-discharge ion-source, irradiated with 1 μ A 600 MeV protons.

Fig. 8

Production yields of isotopes of Hg, Tl, Pb, Bi, Po and At from a uranium carbide target (9.7 g U/cm²) at 1950 °C, equipped with a hot plasma-discharge ion-source, irradiated with 1 μ A 600 MeV protons

Fig. 9

Production yields of SrF⁺ ions from a 47 g/cm² Nb foil target at 2100 °C equipped with a W surface ionizer and a CF₄ leak, irradiated with 1 μ A 600 MeV protons.

Fig. 10

Production yields of YF₂⁺ ions from a 47 g/cm² Nb foil target at 2100 °C equipped with a W surface ionizer and a CF₄ leak, irradiated with 1 μ A 600 MeV protons.

Fig. 11

Production yields of LuF⁺ ions from a 122 g/cm² Ta foil target at 2200 °C equipped with a hot plasma-discharge ion-source and a CF₄ leak, irradiated with 1 μ A 600 MeV protons. Anode voltage: 200 V

Fig. 12

Production yields of HfF_3^+ ions from a 122 g/cm^2 Ta foil target at 2200°C equipped with a hot plasma-discharge ion-source and a CF_4 leak, irradiated with $1 \mu\text{A}$ 600 MeV protons. Anode voltage: 110 V

Fig. 13

Production yields of Ca^+ and CaF^+ ions from a 40 g/cm^2 Ti foil target at 1600°C equipped with a W surface ionizer and a CF_4 leak, irradiated with $1 \mu\text{A}$ 600 MeV protons.

Fig. 14

Production yields of Sc^+ and SrF^+ ions from a 40 g/cm^2 Ti foil target at 1600°C equipped with a W surface ionizer and a CF_4 leak, irradiated with $1 \mu\text{A}$ 600 MeV protons.

Fig. 15

Production yields of isotopes of Mn, Cu, Zn, Ga, Ge and As from a ZrO_2 felt target (6.3 g Zr/cm^2) at 2000°C equipped with a hot plasma-discharge ion-source and irradiated with $1 \mu\text{A}$ 600 MeV protons.

Fig. 16

Production yields of COSe^+ ions from a ZrO_2 felt target (6.3 g Zr/cm^2) at 2000°C equipped with a hot plasma-discharge ion-source and irradiated with $1 \mu\text{A}$ 600 MeV protons.

Fig. 17

Production yields of isotopes of Ne, Na and Mg from a SiC target (19.0 g Si/cm^2) at 1600°C , equipped with a hot plasma-discharge ion-source and irradiated with $1 \mu\text{A}$ 600 MeV protons.

Fig. 18

Production yields of AlF^+ ions from a SiC target (19.0 g Si/cm^2) at 1600°C , equipped with a hot plasma-discharge ion-source and irradiated with $1 \mu\text{A}$ 600 MeV protons. The source of Al vapour was a contamination of the target material.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

FIG. 8

Fig. 9

Fig. 10

Fig. 11

Fig. 12

Fig. 13

Fig. 14

Fig. 15

Fig. 16

Fig. 17

Fig. 18