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DESIGN STUDY OF THE PROPOSED SIN-ISOLDE FACILITY

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ABSTRACT

A description is given of the plans for an on-line isotope separator facility intended for the Swiss Meson Factory SIN at Villigen. The installation is designed to accept a beam of 590 MeV protons in an intensity of up to 100 μ A. This installation could produce mass-separated radioactive beams of 100 nA (corresponding to 20 Curies of one isotope at saturation) for the most abundant reaction products.

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1. INTRODUCTION

It has gradually become clear that an on-line isotope separator coupled to a high-energy proton accelerator is an extremely powerful tool for studying far unstable nuclei, both on the neutron-rich and the neutron deficient side of the beta-stability line. The basic reason for this is the large penetrating power of high-energy particles, which allows the use of targets with thickness of 200 g/cm^2 or more. Full use of this advantage has been made possible by development of new target-ion-source techniques to provide clean and intense beams of the elements of interest as well as new techniques for experiments that make use of these beams.

The relevant experimental techniques have recently been reviewed by Ravn [1]. Much of the development has taken place within the last few years; as examples we may mention the use of refractory targets (e.g. uranium carbide at 2000°C) [2] and recent very promising results with negative ion beams of halogens [3].

We shall not here discuss the experiments that make use of beams of radioactive ions but refer instead to a number of recent reviews [4-7]. The main topics studied or foreseen at CERN's on-line isotope separator ISOLDE (from Isotope Separator On Line) are summarized in Table 1, which may serve to give the casual reader an impression of the possibilities at this kind of installation.

The present paper describes a design study of an improved ISOLDE designed for the Swiss meson factory SIN at Villigen. The original ISOLDE [8], which went into operation in 1967, was modified [9] in 1973-74 to essentially the present installation, called ISOLDE-2. This modification has led to an increase in the output ion beam intensities of close to a factor of 1000 and provided essential improvements in the experimental areas. In addition a simple form of remote handling was introduced in the highly radioactive target area.

At the present stage, our study has dealt mainly with feasibility, lay-out, safety and logistics of the proposed SIN installation, which is foreseen to operate routinely at $100 \text{ }\mu\text{A}$ protons as against the present maximum of $4 \text{ }\mu\text{A}$ at ISOLDE-2. We give here the main conclusions

2. DESIGN AIM

At the time when an ISOLDE installation at SIN could come into operation, the extracted beam intensity is expected to be 1-2 mA of 590 MeV protons. The ISOLDE operation mode would be in sharing with an estimated maximum intensity on the target of $100 \text{ }\mu\text{A}$. This intensity, at present, seems to represent an approximate technological upper limit, and would be used for about 20% of the ISOLDE beam time only. The typical intensity during the remaining time would be $20 \text{ }\mu\text{A}$. The planning is in the basis of a yearly operation time of 4000 hours. In most experiments, the fine structure of the proton beam is of no major importance. It would, however, be

attractive to use a high intensity pulsed mode for the study of the decay of extremely short lived activities. As an example one may take ^{11}Li ($T_{1/2} = 8.6$ ms) where one could use a 1 mA, 10 ms burst repeated every 100 ms. The main technological problem with such a mode is the stabilization of the separator acceleration voltage.

3. LAYOUT OF THE SIN-ISOLDE FACILITY

A cutaway view of the new ISOLDE installation is shown in Fig. 1. A major improvement from the existing ISOLDE-2 is that the facility is foreseen to have a fully equipped target handling laboratory (active handling bay and hot-cell area) which is separated from the experimental area and with individual access to it. The target and isotope separator zone is fully remote controlled and directly linked to the hot-cells and the hot-laboratory via the target loading zone. The hot-bay is separated from the experimental floor by the isotope separator shielding and a water-cooled beam-dump. The ISOLDE control room is placed on top of the shielding which gives the advantage of minimum cable lengths to the high tension terminal of the machine.

The dimensions of the hall is $30 \times 46 \text{ m}^2$ with an overall height of 23 m. The whole area is served by a 20 t crane. The geographic location of the ISOLDE hall at SIN and the proton beam path is shown in Fig.2.

3.1 Isotope Separator and Target Area

The detailed design of the isotope separator is very much an open question. There has been a great progress in the construction of high-resolution, high-transmission separators in recent years [10] and in the final installation one would obviously consider the latest developments in this field. At the present stage of our design study, however, this plays no major rôle and for planning purposes we have simply assumed a separator similar to the one used at ISOLDE-2.

The highest radiation level is found in the target area. The dose rates to be expected have been estimated by linear scaling of the rates measured at ISOLDE-2 [11]. Fig. 3 shows as an example the rates around a target irradiated for 48 hours with a 100 μA proton beam. The levels are of a magnitude that excludes manual intervention : remote handling is clearly necessary. The target-ion-source unit itself contains the major part of the radioactivity and the routine target changes will be made with the aid of a modified industrial robot. The robot carries the targets from the acceleration chamber either to shielded target containers or to the hot cells. In addition to the radioactivity from the target there is a residual induced activity originating from secondary particle activation and radioactive vapours condensed inside the acceleration chamber. The isodose curves around this chamber after one year of operation are shown in Fig.4. One finds that

even this activity level excludes manual interventions and it is also foreseen to remove the acceleration chamber by means of the robot. In addition, a set of master slave manipulators, operated from the loading zone, will be installed for special work in the target area.

With the planned level of operation of SIN-ISOLDE the acceleration stage of the isotope separator will be exposed to very high doses. The estimates for the most sensitive parts of the system are as follows :

- 1.2 · 10⁹ r/y at the first insulator and the target coupling mechanism,
- 1.4 · 10⁸ r/y at the turbo molecular pump,
- 1.8 · 10⁷ r/y at the target and at the analyzing magnet.

These figures are close to the critical radiation damage levels and a yearly exchange of the entire acceleration chamber is foreseen.

The shielding around the target-ion-source and the beam dump have been designed to give less than 0.3 mrem/h at the outer surface. The necessary amount of shielding is shown in Fig. 5 and a detailed account for the basis of this estimate is given in Appendix 1.

3.2 The Hot Bay

The ISOLDE targets that pose the greatest problems from the safety point of view are those containing uranium or thorium. After a typical run with 100 μ A protons, the activity level will be of the order 10⁴ Ci but in addition these targets will contain about 25 Ci of the volatile element radium. Radium is condensed as a thin layer on internal surfaces of the target vacuum chamber and it gives rise to an almost quantitative release of its alpha radioactive daughter radon. Our design has been made to meet the requirements of handling targets of this type.

All surfaces in the target area and in the loading zone have to be easy to clean and without dust corners. The hot cells which connect the hot laboratory to the loading zone will be built with a double confinement together with a 12 cm lead radiation shield.

Special attention must be paid to the ventilation of the hot bay. The area has several rooms and the distribution of pressure has to be ensured so that the air current always moves from lower to higher activity levels. For the hot cells and the target area noble gas and iodine filters are required. Air conditioning for the radioactive laboratories and the target area should include dehumidification to avoid corrosion and H.T. problems.

3.3 The Experimental Area

The size of the experimental area is 420 m² which allows the installation of four beam lines with shielding in between. Electronics for the experiments can be placed on top of the shielding in air-conditioned huts. The height of the hall also allows vertical extension of the beam lines.

An interesting option would be to equip one of the beam lines with a second separation stage. With this one could reduce the presence of cross contamination considerably and it would be of importance in experiments on nuclides formed with extremely small cross sections.

3.4 Layout with two Isotope Separators

One weakness with the lay-out shown in Figs. 1 and 5 is that it only provides one target zone. With the long running periods foreseen and the elaborate safety precautions required, frequent interventions will be difficult. From this point of view, an installation with two isotope separators with separate target zones would be more convenient. One possible lay-out of the SIN-ISOLDE facility with two separators is shown in Fig. 6.

4. CONCLUSION

The on-line facility described here is in our view the ideal installation for meeting the requirements of the field in the late eighties and the nineties. Based on the newest experimental techniques it should be safe and economical to operate and will allow the intensities to be pushed towards the technological upper limits. An important new possibility that opens up is pulsed operation.

APPENDIX 1

SHIELDING AROUND THE SIN ISOLDE TARGET AND BEAM DUMP

The calculation of shielding must be based on the expected maximum proton beam intensity, i.e. 100 μ A and on the recommendation that the dose rate on the outer surface of the shielding should not exceed 0.3 mrem/h. In the forward direction the flux of high energy particles (above 20 MeV) produced by stopping a 100 μ A beam of 600 MeV protons in a thick target or in the beam dump will be :

$$\phi_0 r = 1.7 \cdot 10^{15} \text{ part/sr} \cdot \text{sec}$$

At a distance of 10 m the flux is :

$$\phi_0 = 1.7 \cdot 10^9 \text{ part/cm}^2 \text{sec}$$

giving a dose rate of $5.7 \cdot 10^5$ rem/h. The necessary attenuation factor has to be :

$$A_0 = 1.9 \cdot 10^9 = e^{21.3}.$$

With an attenuation length at 0° of 165 g/cm the thickness of the shield has to be 3500 g/cm². A 10 m thick wall composed of 2.25 m of steel and 7.75 m of ordinary concrete would be adequate.

In a direction of 90° from the proton beam the attenuation factor is decreased to :

$$A_{90} = 2.2 \cdot 10^7 = e^{16.9}$$

demanding a wall thickness of 2000 g/cm².

It is advisable to cover the inside walls of the target area with a 30-50 cm thick layer of marble to reduce gamma radiation back from the activated steel walls.

In the here presented layout (Fig. 5) a possible arrangement of shielding is drawn where source points, particle fluxes and attenuation factors in different directions as well as wall thicknesses have been taken into account. The total shielding would be composed of 2100 t of steel and 3500 m³ of ordinary concrete in form of movable blocks.

Table 1

The present and expected future experimental programmes at ISOLDE

1. CURRENT TOPICS 1978-80

Target and ion source techniques

- Improvements
- Extension to elements not previously available
- New isotopes and half-life systematics

Systematic studies of nuclear structure

- Ground-state spins, moments and isotope shifts (laser techniques, ABMR)
- Nuclear masses by direct mass spectrometry
- Q-values in α, β decay
- Detailed nuclear spectroscopy

Exotic nuclei and rare decay processes

- Light exotic nuclei
- Beta-delayed, $\alpha, p, n, 2n, 3n$ emission
- Strength-functions and statistical phenomena in β, p, n , decays; level densities away from stability

Other applications of radioactive ion beams

- Implantation in solids; studies by quadrupole interactions and the Mössbauer effect
- Ranges of ions in gases; first observation of an optical transition in the francium atom
- Atomic and nuclear effects on the energies of K X-rays
- Radioactive targets for nuclear reaction studies

2. EXPECTED DEVELOPMENTS OVER THE NEXT 5 YEARS

- New optical methods for studies of the atomic hyperfine structure
- Extended use of direct mass spectrometry for mapping the nuclear mass surface
- New target-ion source systems will make it easier to study light exotic nuclei (n and p rich)
- Detailed studies of nuclear spectra in cases of special importance
- More applications to solid-states physics
- More applications to atomic physics

3. PROBABLE DEVELOPMENTS IN THE LONG RUN

- Further applications in nuclear physics
- Isotope production
- Extended use for solid-state studies and maybe for technical applications
- Applications in chemistry and medicine
- Surprises

FIGURE CAPTIONS

Figure 1 : Overall view of the SIN-ISOLDE building. The hot bay is separated from the experimental area by the shielding around the isotope separator and target. Exchanges and transport of target and acceleration chamber to the storage cells and hot cells are made with an industrial robot.

Figure 2 : The geographical location of the SIN-ISOLDE hall. The beam to ISOLDE is guided along the wall of the main building and is directed against the ISOLDE target with the aid of a 90° bending magnet. This location of the ISOLDE hall makes a 20 m extension of the SIN hall necessary.

Figure 3 : Isodose curves in rad/h around a 230 g/cm² Pb target, shown after a 48 hour irradiation with a 100 A 590 MeV protons beam. These expected SIN-ISOLDE dose rates are obtained by scaling of measurements performed at ISOLDE-2 [11]. They are in good agreement with calculations made with the approximate relation of Sullivan [12] :

$$D_{Pb} = 8 \cdot 10^{-12} \phi [t^{-0,4} + (T+t)^{0,4}] \text{ rad/h}$$

where t is the decaytime in hours, T the hours of irradiation and ϕ the number of protons per second in the beam. With the above mentioned parameters the dose rate at one meter distance from the target is calculated to be 4000 rad/h as compared to the measured and scaled value of 6000 rad/h. After decay periods long compared to the irradiation time it is shown by Sullivan [12] that the activity induced in a heavy target as Pb decays as $t^{-1,4}$ whereas that arising from medium Z elements like Fe or Cu follows a t^{-1} law.

Figure 4 : Isodose curves around the acceleration chamber without target after one year of operation i.e. $1,4 \cdot 10^5$ μ Ah and 20 days of cooling. Like in the previous figure the curves are obtained by scaling of measurements from ISOLDE-2. The main source of radioactivity in the acceleration chamber comes from stray beam and secondary particle activation of the steel, copper and aluminium parts of the chamber and the target coupling mechanism. Only a small contribution is from condensed radioactivity inside the chamber. It is therefore expected to decay according to the t^{-1} law and further cooling becomes very unpractical.

Figure 5 : Top view of the SIN-ISOLDE facility. The shielding around the target and the beam dump consists of steel and concrete. The inside walls of the target area are covered with a 30-50 cm layer of marble.

Figure 6 : Possible lay-out of a facility with two separators. This design places the whole installation below ground with vertical beam lines. The cost of excavation is partly compensated by considerable savings in space and shielding, but the beam dump may require special precautions to protect the ground water.

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Fig. 1

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Fig. 5

Fig. 6