THE BIRTH OF ON-LINE ISOTOPE SEPARATION

O. Kofod Hansen
Research Establishment Risø, Roskilde, Denmark.

I have been given to understand that the organizing committee would like me to talk about the early history of the field of isotope separation on line. I shall attempt to comply with this choice of subject by using an unhistorical approach. I shall first tell you about ISOLDE 2 i.e. the most recent version of such a system. And then I shall talk about the way in which the idea was conceived i.e. the idea of combining a cyclotron (or other producer of radioactivity) with an isotope separator. So let me begin with ISOLDE 2 and let me start in the usual modern fashion by stating that I have nothing to do with it and I know nothing of it. These two points are the reason why I talk. I talk about other people's work and therefore I hereby present you with the list of coworking institutes as shown in table 1. There are so many that you can hardly read them.

Table 1.
It would of course be a lot more difficult if I listed the names of coworkers (more than 100).

Fig. 1 shows an artistic version of the ISOLDE lay-out. ISOLDE stands for isotope separator on-line and de was added by some Wagner-fan. Thus the thing is on line. This line is shown in black in the drawing. It transports the 6C2 600 MeV external proton beam to the ISOLDE target area. Here radioactivity is produced and some if it reach the ion source of the separator. Again a fraction of that is accelerated and mass-analyzed in the separator magnet. Unfold many years have gone into the improvement of the efficiency of radioactivity release and of ionization possibilities. Weighable amounts of short-lived radioactivities are produced and collected after separation which in the most favorable cases run into several times 10^10 atoms per sec. A switchyard may direct the separated beam into one of four different beamlines and a fifth position on the floor above is reached after further switching. Thus five major experimental areas are available. Provisions have been made for about 20 different target-ion-source systems and I do believe that all of this illustrates the impressive range of planned and operating experiments where several have given results to be presented at this meeting.

Fig. 2. illustrates the previously black but now hidden line unto which the separator is attached. What is shown is focusing magnets and target area, which is
an ion source area. Also the ion accelerator is shown. Behind all of this is the beam dump, and to the right in the picture the ion source storage complete with remote handling (ion sources do become quite radioactive).

Fig. 3 shows the four-way switchyard with beam lines going towards the experimental area. This area is shown in Fig. 4.

All of these pictures illustrate an impressive amount of equipment like pumps, bending magnets, focusing magnets, electronics, etc. In addition one has the control panel and the control systems used by the experimental groups. The entire installation involves a considerable number of on-line computers in the medium-size-range.

The program is equally impressive. In table 2 I have chosen to reproduce P.G. Hansen's list which he has used in 1975 in order to impress his peers and his superiors. Much of this has been perfected recently and is reported here at Cargèse.

Table 1. ISOLDE main lines of research.

1. Detailed spectroscopy of excited nuclear levels; nuclear structure.
2. Target and ion-source development.
3. Atomic spectroscopy by optical pumping.
4. Hyperfine spectroscopy by atomic beam magnetic resonance techniques.
5. Nuclear masses by direct mass-resolution spectroscopy, \( M_d \approx 1 \mu \text{amu} \).
6. Nuclear masses through \( Q \) values.
7. Alpha decay of very neon-deficient nuclei.
8. Targets of radioactive nuclei; for fission 3-5 mg amounts of 20 mg/cm³.
9. Isotope and isotope shifts by crystal-diffraction spectrometry.
10. Time-delayed gaseous and solid, fluctuations.
11. Analysis of ions in gases.

Table 2.

Thus all in all a considerable program both technologically and for physics research. And here ends my summary of the present situation with a general impression of "Glory to you all" also those of you who are on-line to other machines and devices.

Before ISOLDE 2 there was ISOLDE 1 which I shall omit. Thus I shall go back to 1951 and before and tell you about the invention of ISOLDE 0.

Zero is appropriate because we knew nothing of the word "on-line" at that time.

The work in question was carried out at the Bohr institute and it began when the said institute had the shape shown in fig. 5.
One had however expanded with building K in 1951 and that has continued over the years so my present desk at WBI is somewhere in midair on this picture. The reason that ISOLDE was invented was that under the conditions shown the cyclotron and the isotope separator were placed close together. When in 1952 the far-away new building was finished and the cyclotron moved, all connections between the two instruments were severed.

The list of collaborators on ISOLDE 0 is easily produced (Fig. 6). It consisted of this young man who is eagerly explain-

![Fig. 6.](image)

ing the works of an isotope separator to some unknown visitor. I am sure that you recognize him but we have of course both grown older. The reason that we worked together was that he was running an isotope separator and I was running a cyclotron. In my description of ISOLDE 2 I forgot completely to mention the group of a little less than 100 persons who run the SC 2. You could in principle add them to the list of ISOLDE coworkers.

![Fig. 7.](image)

An isotope separator is some type of instrument like this (Fig. 7) and I have already explained that it consists of ion source, accelerator section, bending magnet and target area. Also here the ion source is at high tension (scores of kilovolts) thus the corona shield. Inside this area the essentials as shown in Fig. 8.

![Fig. 8.](image)

We had to do a lot of manipulations with the ion source and particular its gas inlet. This work had already started when J. Koch, P. Kristensen, W. Drost-Hansen and I had carried out off-line separations of long lived noble gases from uranium fission in 1949.

A cyclotron needs a big magnet which I first want to show in line-drawing (Fig. 9) with its poles, yoke and coils.

![Fig. 9.](image)

The same thing did look like this (Fig. 10) in reality. Don't let the tiles mislead you and think that it is a baker's oven.
Into such a magnet one inserts an RF-system shown in Fig. 11, only at that time one didn't know that it was a system (modern usage of words was of course non-existent). The thing was then controlled from the control panel which is shown in Fig. 12.

The result was a beam internally or an external one as depicted in Fig. 13.

In the early days you could see the beam from the control room, there was no shielding.

We have now looked at an isotope separator and a cyclotron. We then put them together and have ISOLDE 0 as shown in Fig. 14.

The processes are: 1) Internal beam hits internal beryllium target, neutrons are produced, 2) some of the neutrons slow down in paraffin around a uranium container which is filled with a mixture of finely ground uranium oxide and baking powder, 3) neutrons hit uranium and make fission, out come fission products, 4) Those fission products which don't get stuck in solid material notably Kr and Xe are transported by CO₂, H₂O and NH₃ decomposition products from the baking powder (decomposing under vacuum) to the cooling trap near the isotope separator, 5) Then follows separation, collection and measurement. The connecting link between isotope-separator and cyclotron was a two inch metal tube on 50 kV i.e. the accelerating hightension of the separator. It was a
sparking experience.

Sometimes one tried to do fast chemistry. This consisted in dismantling the separator target chamber, snatching the collector foil and dropping it into a suitable liquid while one was running fast to the elevator (an unknown student was strategically placed near the elevator reserving it for our use and holding the door). Then one did some precipitation and filtration. Finally we counted $\alpha$- and $\gamma$-rays. All this was done in the newly installed radiochemistry laboratory. We didn't really succeed and I must confess that I detest doing chemistry.

This now brings me to the discussion of technicalities. Chemistry was an essential part of the show. First the cyclotron had to have a chemical coating of glyptal paint almost every morning. The fabrication of NaCl targets for the bread and butter work of providing the medical profession with Na$^{24}$ and especially the "remote" handling of the radioactivity had better not be mentioned in modern society. Next came beryllium targets where smoke and poison together with radioactivity was the inevitable working atmosphere. I am still surprised that Lassen didn't die from it. Similar comments may be made for the UO$_2$ production which took place on the top level of the institute for mathematics with an interim chimney out the window (brown and green smoke). Grinding the stuff was worthy of an old-fashioned pharmacist. Let that be enough for chemistry and let us turn to electricity. Here I have a couple of figures to show you. Thus in Fig. 13 you see the RF power supplying triode in the main cyclotron circuit. All homemade. The filament was a simple tungsten wire bent into the shape of a hairpin.

![Fig. 15.](image)

I remember that it is not easy to bend tungsten with simple means - but of course the filaments burnt through and had to be renewed ever so often. Much of the work was routine and since but a few persons were involved (Borge Madsen, Høffer Jensen, Lassen and myself) there was no detailed record of cables etc. We all knew more or less all about it. The fail-safe cooling system was ensured by the gadget shown in Fig. 16. The thing was quite moist and since we didn't use low tension controls the result was that we had 220 volts everywhere.

![Fig. 16.](image)

Sparks were running along the floor to the sewage system. The fuse was made of sheets of copper foil. However, not all wires were active. Once, Lassen fell down a ladder, grabbed at the nearest something, a bunch of cables, and broke the lot. He didn't hurt himself but I was looking in dismay at twenty-odd wires with no colour code or any other identification on them. "Never mind", said Lassen, "let us try it if (the cyclotron) works." And so we did, and so it did.

The separator had its production line. It made separated stable targets for the van-de-Graaf and separated radioactive krypton for spectroscopy. The instrument itself was perhaps slightly more in professional style than the cyclotron - but not much. You have to remember that most of the technical marvels to which you are all accustomed are new.

We used radicistues in our electronics for the first go at ISOLDE-O work, but only a few years before, the idea of a better utilization of the short resolution time of Geiger-Muller counters compared to mechanical counters had been introduced at Blegdamsvej by Ambrosen. He had used gasfilled triodes for his scalers. The number of steps from gasfilled triodes to modern miniatures is almost incredible.

You may now ask the questions: Why did one invent "ISOLDE O"? The answer to that one is (I think) the only point where I want to be relatively serious, in this little historical exposé. J.C. Jacobsen had taken an interest in the at that time interesting experimental question concerning $\beta$-decay (nowadays called weak interactions). The experimental question was: If one omits ideas like neutrinos then energy is missing in nuclear $\beta$-decay, how
about momentum? Like all good experimental questions this one cares a damn about theory (e.g. the theory of relativity.) This now meant recoil measurements. And Jacobsen realized that, to avoid molecular final state interactions, one should use one-atomic gases like Kr or Xe for the experiments and apply daughter radioactivity through the tracer method for the detection of recoils. First we used Kr88 and found that momentum was missing. Fig. 17 shows J.C. Jacobsen between our apparatus and the cyclotron. Then one invented ISOLDE-0 and searched for other candidates, found that Kr89 was possible, and P. Kristensen and I carried out the Kr89 job.

Thus there was a very good and precise motivation for the invention of ISOLDE-0 and permit me to finish this talk with the wish that all of you who work at ISOLDE-2 may keep this point in mind and search for experiments to do, which shed light on precise questions in physics and let such experiments have priority relative to those which merely fill in the gaps in tables of raw data on overcomplicated issues.

My sincere thanks are due to the Niels Bohr archives for the permission to reproduce old pictures.