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THE ISOLDE COLLABORATION STATUS REPORT AND REQUEST FOR MACHINE TIME 1979-1980

1. INTRODUCTION

The past year probably has been the most productive one in the history of the Collaboration. The cyclotron and the isotope separator have operated well and have set new records for the operation. Several of the key experiments at the reconstructed facility have completed their data taking and have left the floor and several new experiments are in progress. The publication list (appendix 1) gives a good overview of the activities of the Collaboration in the past year; a complete coverage of the scientific results is not possible in the present report, which can only deal with the main lines.

2. STATUS OF THE FACILITY

2.1 Operational statistics

The salient features of the utilization of the ISOLDE Facility have been given in the Coordinator's report, enclosed as appendix 2. Since operation of ISOLDE has always been limited essentially by manpower, it is gratifying to note that a number of improvements in the separator and especially in the target-ion-source design have gradually allowed a more intense utilization of the Facility. The graph and table 1 of appendix 2 show that the original design aim of 180 shifts/year was surpassed in 1977 and that in 1978 227 shifts were used. As expected, the average number of parallel users dropped from 2.3 to 1.5 owing to longer runs and more specialized experiments with fewer possibilities for sharing.

Table 2 of the appendix shows that a total of 13 target-ion-source systems now have been operated during the four first years of operation (1975-1978); this demonstrates that ISOLDE still is able to commission about three new systems per year. The total number of possible systems with today's experimental technique is believed to be around 40.

The space problems in the experimental areas have been severe over the past year but some improvements are in sight. The EP Division is now adding ca. 80 m^2 to UR-10, the electronics area for users. Furthermore there are plans to move the ISOLDE Control Desk away from UR-9 in order to get room for one more measuring station, which will be connected to beamline 2.

2.2 The SC beam

The ratio of SC beam time delivered to beam time scheduled has been better than 99%; the ISOLDE Collaboration thus has all reasons once again to express its gratitude to the PS staff both for high technical standards and for a pleasant collaboration.

As most of the ISOLDE experiments are not intensity limited, the operation has typically been in the sharing mode with $\approx$ 1.5 μA of protons on the target, but for several long runs, the full beam of 2.8 μA (external) has been used. Heating, radiation damage and radiation safety are becoming major concerns, the latter especially because of the possible release of airborne radioactivity from the target unit and acceleration stage. Some of the molten-metal targets are now being heated entirely by the proton beam.

The most important beam development during the year has been the first experiments with the 910 MeV ^{3}He beam. These experiments show a large increase in the yields from deep-spallation reactions, such as light Tl and Fr from targets of UC_2 and ThC, see figure 1.

The next important step forward will be the 86 MeV/amu ^{12}C beam, which, barring unforeseen problems, will be available in autumn of 1979. As is clear from ISOLDE's proposal (CERN-SCC/78-12/SCC-P-6 of April 25, 1978) this research represents a new line in the scientific programme of the Collaboration in that it aims at using the mass separator of ISOLDE and the Orsay mass spectrometer (placed in the proton room of the cyclotron) to study reaction cross-sections. There are no immediate plans for production runs.

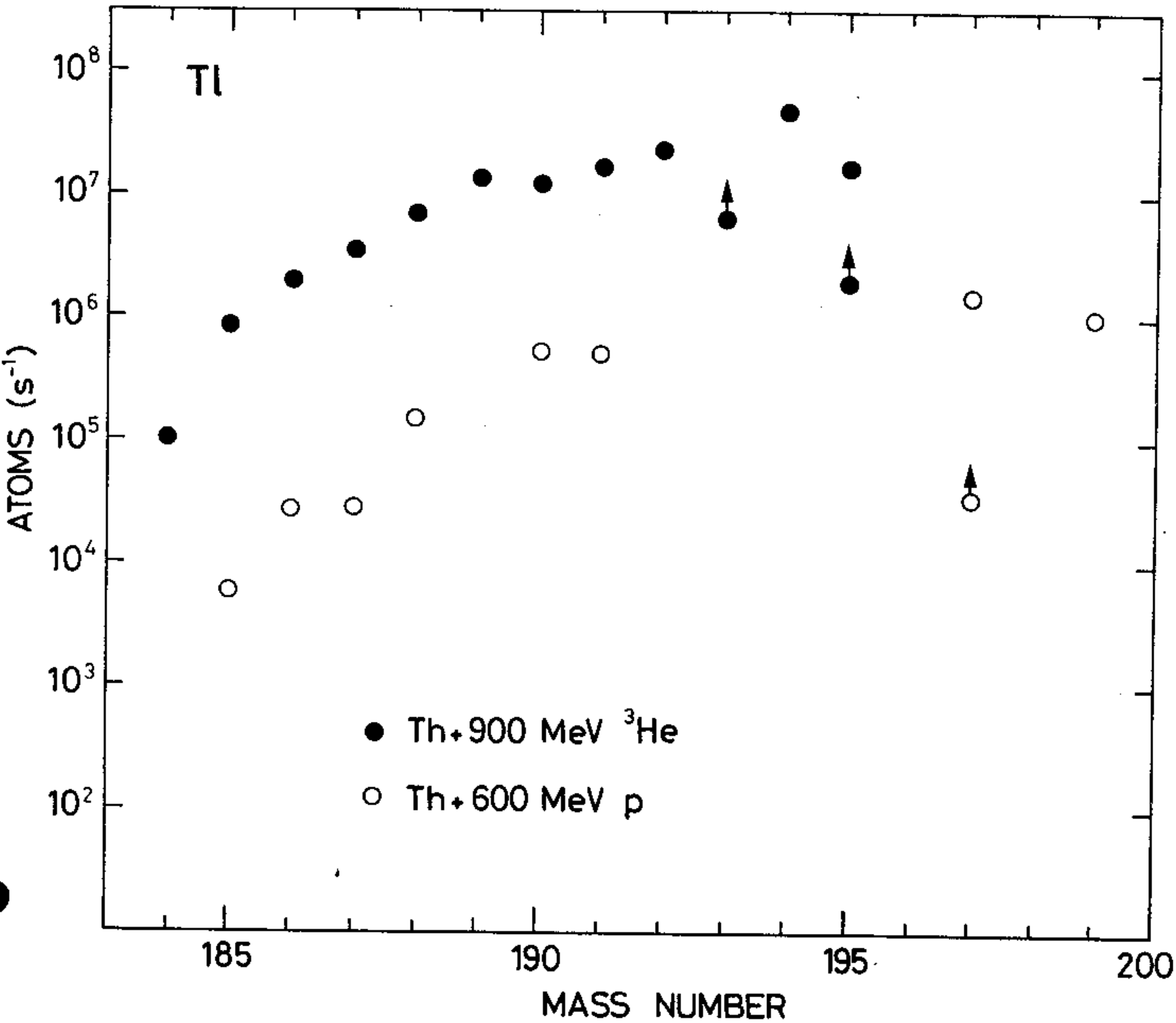


Fig. 1 : Experimental yield curves, given as atoms per second in the mass-separated beams at ISOLDE. The points represent the production of thallium from a thorium carbide target (13 g/cm^2) irradiated with 1 μA protons or 2 μA $^3He^{++}$. It is clearly seen that the yields obtained with 2 μA $^3He^{++}$ corresponds to what can be obtained with a 100 μA proton beam.

2.3 The target and ion source

The development of new experimental techniques continues to be absolutely essential for ISOLDE's work. A comprehensive review of this field will be given in a paper by H.L. Ravn (in preparation). The most important development has probably been a high-temperature surface ionization system that has allowed the study of the elements lithium, sodium and potassium. It has also become clear that ISOLDE has unique possibilities for studying neutron-rich isotopes via high-energy fragmentation and fission reactions on targets of carbides of uranium and thorium. As an example of a combination of the two techniques, figure 2 shows the yields of sodium and potassium isotopes.

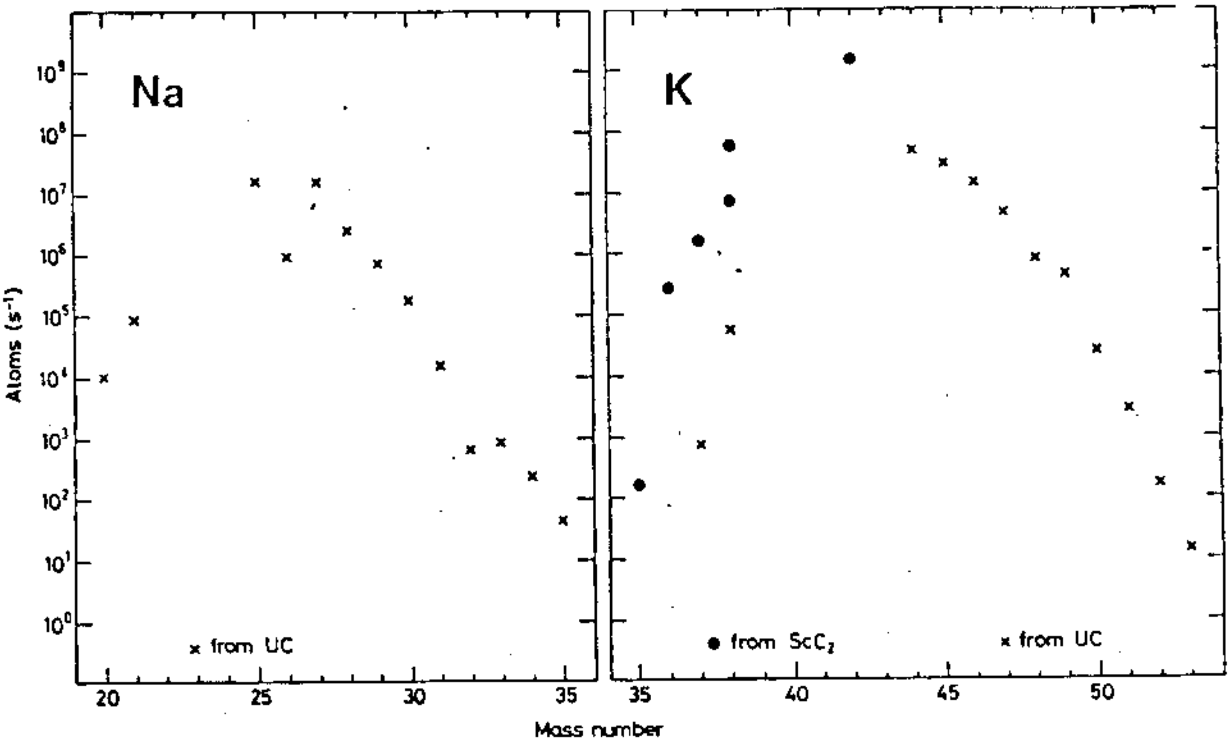


Fig. 2 : Observed yields of sodium and potassium isotopes corresponding to a 1 μA beam of 600 MeV protons impinging as a 14 g/cm^2 target of UC$_2$ and a 32 g/cm^2 target of ScC$_2$. Note especially the high yield of ^{35}Na, first discovered at the CERN PS.

The surface ionization systems also have allowed the production of beams of indium and thallium. Tests in progress as this report is being written indicate that the system for separation of the halogens as negative ions now has been successful. Further improvements of existing systems are also possible in some cases. Thus a redesign of the system for producing Cd recently led to an improvement of a factor 5 in intensity.

Special thin target systems with vacuum connection to to the cyclotron beam line are being designed for the ^{12}C tests in the autumn.

3. THE EXPERIMENTAL PROGRAMME. I. PROPERTIES OF THE NUCLEAR GROUND STATES

3.1 Masses

The first experiment using mass spectrometry for measuring ground-state masses of radioactive atoms was carried out at the CERN PS a few years ago. A new series of experiments at ISOLDE now has used a Mattauch-Herzog spectrometer with a resolution of about 5000 to measure masses also of alkali atoms heavier than sodium. As an example figure 3 shows the results (represented as two-neutron separation energies) for the element rubidium (Z = 37); the data are seen to extend from the self-conjugate ^{74}Rb ($T_{\frac{1}{2}}$ = 60 ms) to ^{96}Rb. This experiment has already finished data taking and was removed from the floor in 1978 to give space for a new laser experiment.

A six-gap magnetic beta spectrometer of the "orange" type has been put on line to study Q values in ($\beta^{\pm}$ decay. Such studies are considered important as they serve to provide links between alpha-decay chains and nuclei near stability with known masses. A few Q_{β} values can therefore lead to important extensions of the mass surface.

3.2 Optical spectroscopy

The mercury experiment has now been completed. It began with optical pumping measurements about 10 years ago and has

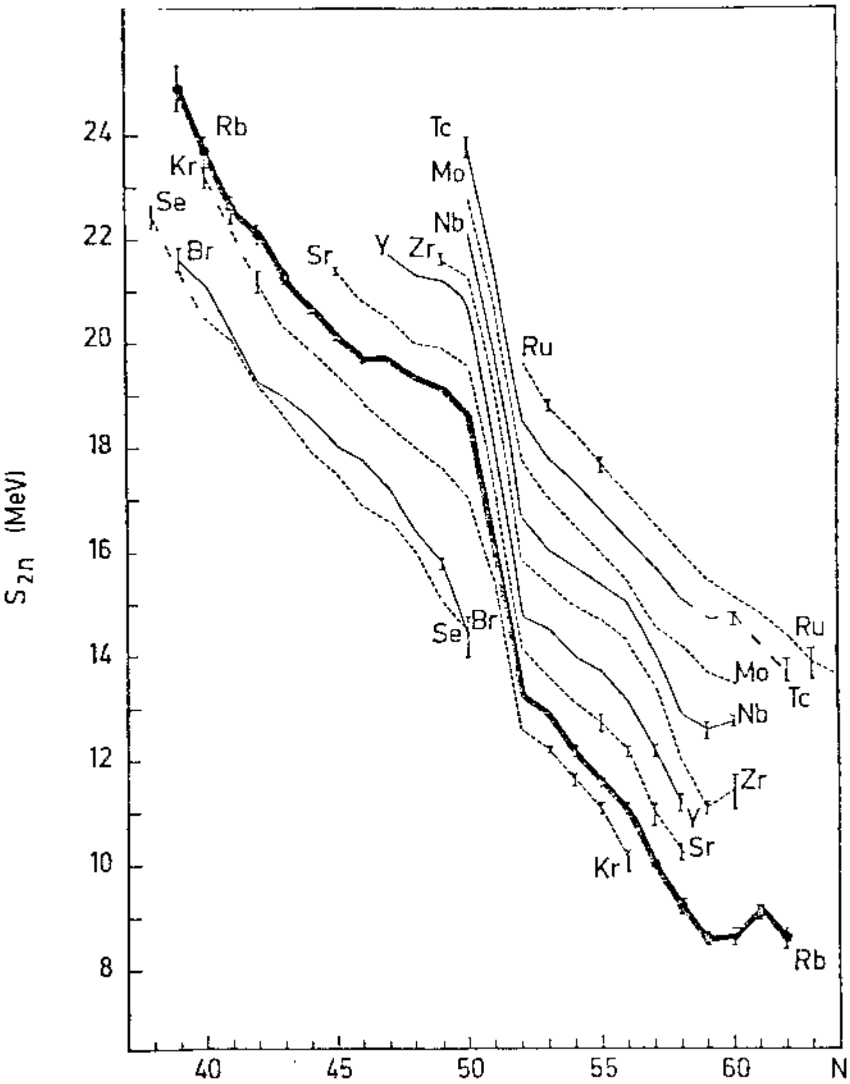


Fig. 3 : Experimental two-neutron separation energies S_{2n} as a function of the neutron number of the heaviest of the pair $N, N - 2$. The heavy line represents the results for rubidium obtained by Epherre et al. (1979) while values from neighbouring elements are from the 1977 mass adjustment (Wapstra and Bos, 1977). The rubidium data are influenced by the following effects : (i) the increased binding at the lighter masses is largely due to the Wigner term, linear in the absolute value $|T_Z|$ of the isospin projection, but may also contain a substantial contribution from the existence of a deformed region near ^{80}Zr. (ii) A strong drop at $N = 50$ representing the well known major shell, and (iii) a smaller drop at $N = 56$, presumably representing the closure of the $D_{5/2}$ subshell. Finally, (iv) the bump at $N \geq 60$ seems a clear indication of the onset of a region of deformed nuclei.

later been pursued by direct laser spectroscopy. A summary of the results is not possible within the limits of the present report, which can only point briefly to the two main findings during 1978 : (i) the discovery of an isomer pair in ^{185}Hg which differ in $<r^2>$ by as much as 0.52 ± 0.02 fm^2, by far the largest isomer shift found in any nucleus and (ii) the observation of a systematic trend in the even-odd radial staggering for a long sequence of $13/2^+$ isomers. A combination of laser and atomic-beam techniques has served to study spins, moments and radii of heavier alkalies. The behaviour of the caesium isotopes accross the N = 82 magic number is especially striking.

A new experimental concept is the use of collinear laser spectroscopy. In this technique, a laser beam travels inside the ion-beam from the isotope separator. After neutralisation of the ions in a charge-exchange cell, resonantly scattered photons are detected as a function of the frequency of the light. It is possible to tune the frequency to resonance through the Doppler effect. The principle has been demonstrated at Mainz University, and a first ISOLDE experiment is now in preparation.

3.3 Atomic-beam magnetic resonance

This technique continues to be one of the most productive at ISOLDE. A typical result is the sequence of caesium spins and magnetic moments shown in Table 1, where the onset of spin 3/2 at mass 143 signifies the beginning of a deformed region, so that the $g_{7/2}$ shell model state leading to spin 7/2 for the lighter caesiums is replaced by the $3/2^+$ [422] Nilsson state.

Table 1

Element	Mass number A	$T_{1/2}$	Measured spin I	Dipole constant a MHz	Magnetic moment μ_I n.m. a)
$_{55}$Cs	138	32.2 min	3 b)	728.1(6)	0.701(7)
	139	9.3 min	7/2	2405(8)	2.70(3)
	140	64 sec	1	±417.6(5)	±0.134(2)
	141	24.7 sec	7/2	2155(6)	2.42(3)
	142	1.68 sec	0		
	143	1.68 sec	3/2		
	144	1.06 sec	1		
	145	0.61 sec	3/2		

a) A hyperfine anomaly relative to the stable isotopes ^{85}Rb and ^{133}Cs of 1% is assumed.

b) Measured by other groups.

4. THE EXPERIMENTAL PROGRAMME. II. NUCLEAR SPECTROSCOPY.

4.1 Low-lying levels

A large number of studies deal with properties of excited levels. As an example, figure 4 shows the measured levels in ^{116}Xe abserved from the beta decay of ^{116}Cs, and also a comparison with a theoretical calculation based on the "interacting-boson approximation (lBA)".

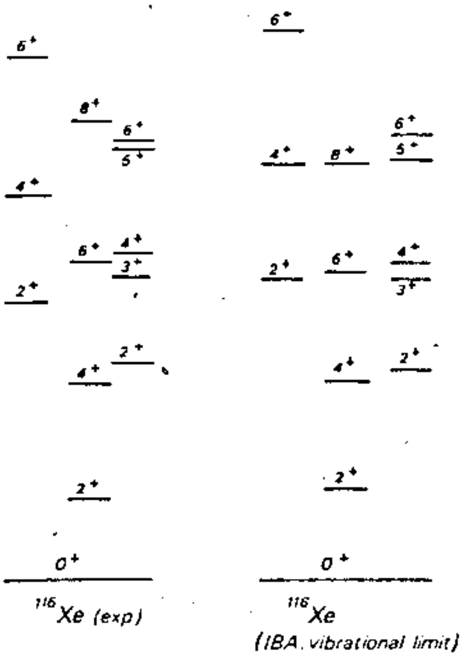


Fig. 4 : Measured and calculated states in ^{116}*Xe.*

Other experiments have dealt with beta-decays of isotopes of argon, potassium, rubidium, cadmium, mercury and francium isotopes. As an example, figure 5 shows additional evidence (in the form of a systematics for low-lying 2^+ levels) for the onset of a new deformed region near N,Z = 60,40. The 129.2 keV 2^+ level in ^{100}Sr when scaled with the usual $A^{-5/3}$ law is the lowest rotational state found in a heavy nucleus. Lower values are obtained for certain isomers, in particular the fission isomers. It is interesting to note that Z = 40 has "chameleon character"; it is magic for both spherical and deformed shapes. Experiments in preparation will deal with the extremely interesting dougly-magic region around $^{132}_{50}$Sn.

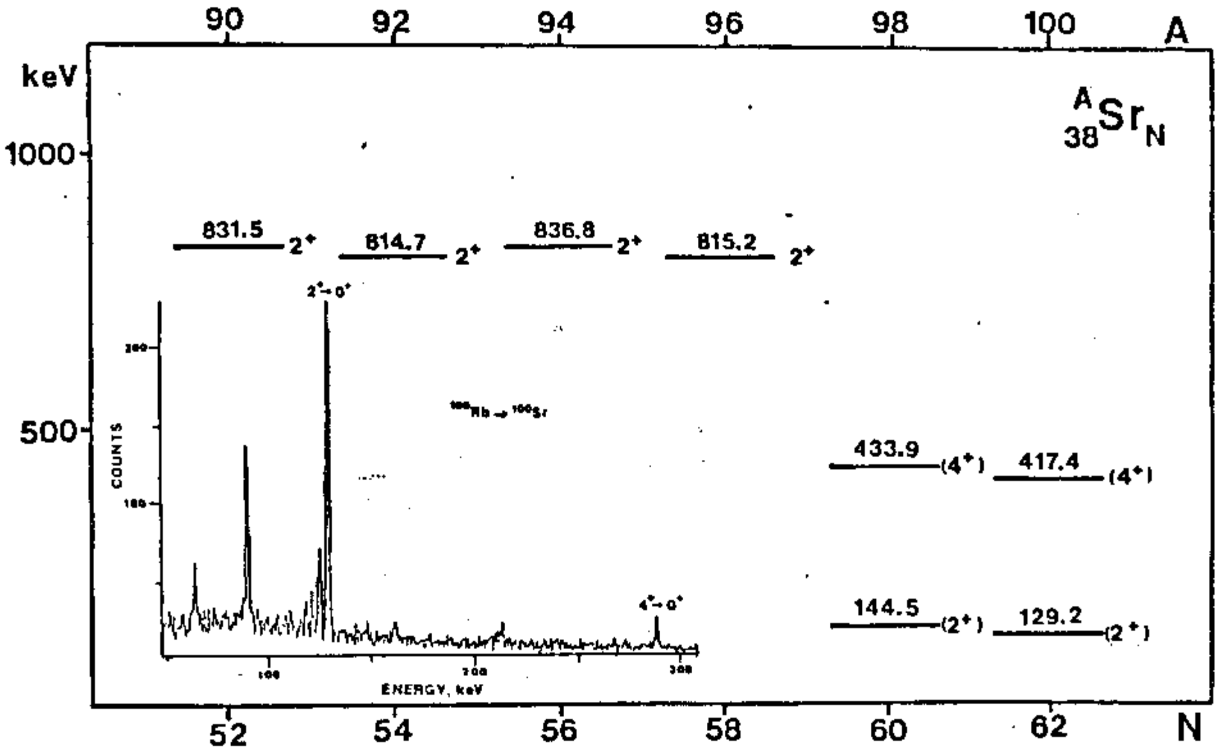


Fig. 5 : Excited levels in isotopes of strontium (Z = 38) and (inset) the gamma-ray spectrum of ^{100}*Rb.*

4.2 Delayed-neutron emission

A new programme uses ^{3}He ion chambers to study neutron spectra following β^{-} decay of extremely neutron-rich nuclei. The most striking result probably is the discovery of beta-delayed two-neutron emission from 10 ms $^{11}_{3}$Li, an isotope first discovered at the CERN PS. The spectrum (figure 6) shows a symmetric broad distribution with a dip at 0.8 MeV; this is interpreted as the decay of a ^{11}Be resonance at 8.84 MeV to ^{9}Be and two neutrons.

4.3 Strength functions and statistical properties

Experiments on average and statistical properties in nuclear beta decay are continuing. A measurement of the fine structure in the ^{99}Cd spectrum combined with fluctuation analysis has permitted the determination of the level-density parameter *a* for ^{99}Ag. The result shown in figure 7 is a striking

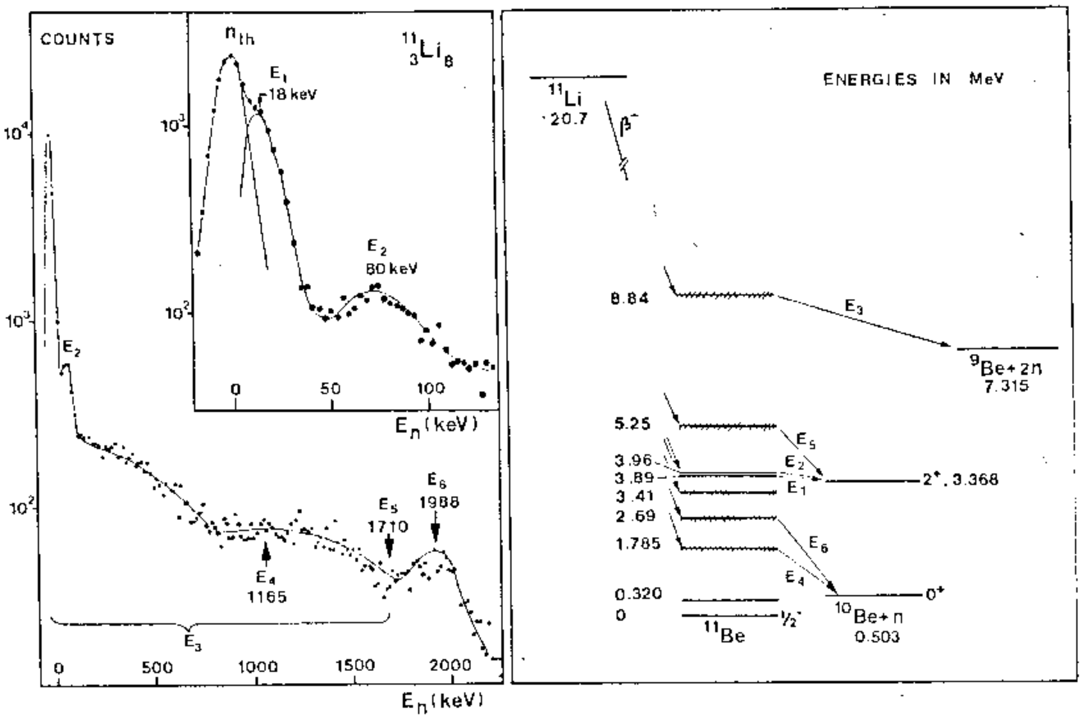
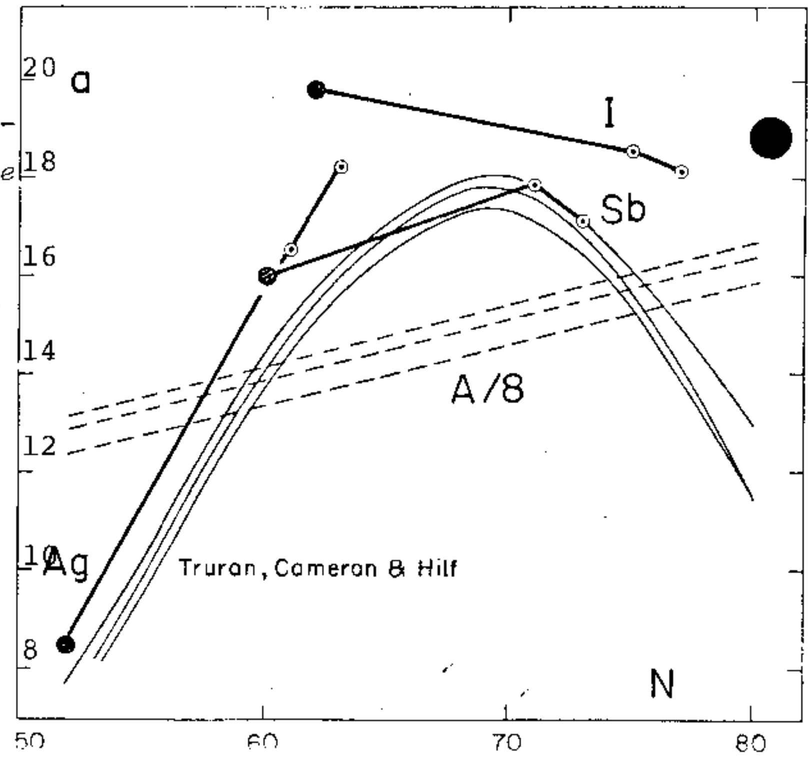


Fig. 6 : The left shows the neutron energy spectrum from ^{11}Li. The broad distribution extending to 1.6 MeV is interpreted as due to two neutron break-up, most likely of the 8.84 level in ^{11}Be, the level scheme of which is known from the (t,p) reaction (right figure).

Fig. 7 : The level density parameter a as a function of neutron number N for the elements Ag, Sb and I. The large points for neutron-deficient nuclei have been determined from fluctuation analysis of delayed-proton spectra. Note the level density depends strongly on a and on excitation energy E : approximately as exp(2 $\sqrt{aE}$).



confirmation of the semi-empirical formula of Truran, Cameron and Hilf and also gives some of the first evidence for the double-magicity of N,Z = 50,50.

5. THE EXPERIMENTAL PROGRAMME. III. ATOMIC AND SOLID-STATE PHYSICS

5.1 Optical spectroscopy of the francium (Z = 87) atom

A combination of atomic-beam and laser techniques mentioned in section 3.2 have permitted the first observation of an optical transition in francium, the D_2 line at a wave length of 718.025 ± 0.015 nm. This element had remained the only one with $Z < 100$ for which no optical transition had been reported. This discovery will permit a study of nuclear properties of francium through the optical hyperfine structure, which has already been observed in a number of cases.

5.2 Implantation of radioactivity

Although high intensities usually are not essential in implantation experiments, this type of research probably constitutes a major and, until recently, unexploited use of on-line installations. One possibility that goes beyond what can be done off-line is to implant activities that subsequently through beta-decay processes give rise to the element or isotope of interest. Experiments at ISOLDE have until now made use of implanted radioactivity for low-temperature experiments, perturbed γ-γ angular correlations for the study of quadrupole interactions in solids, and Mössbauer spectroscopy. Radioactive beams have also been used for a study of ranges of slow heavy ions in gases and an experiment to investigate reflection coefficients of radioactive ions.

5.3 Shifts in the energies of K X-rays

The intense sources of electron-capture radioactivity available at ISOLDE have permitted a study of shifts in the energies of K X-rays with very high precision. The measurements are made with a crystal-diffraction spectrometer in the DuMond geometry; an important new feature is a special double source arrangement which permits a comparison of the energies of two sources with an error as low as $2 \cdot 10^{-4}$ of the natural K line width. The experiments have provided the first observation of shifts due to the 1s hyperfine structure, an effect which accounts entirely for the measured energy difference of 0.112 ± 0.011 eV between Xe $K_{\alpha 1}$ X-rays from sources of ^{131}Cs and ^{132}Cs. The hyperfine shifts in electron-capture sources of K X-rays are brought about by a new selection rule in the atomic F quantum number, the origin of which is illustrated in figure 8.

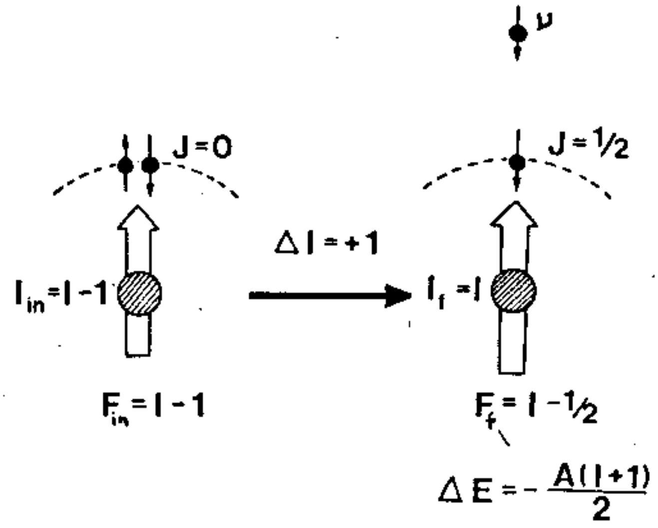


Fig. 8 : The F selection rule for the EC beta decay population of the hyperfine levels. In the example given here, it is assumed that the initial state has a nuclear spin of (I=1) and a full K shell, so that the total angular momentum is F_i = I=1. The nucleus decays by an allowed (or "quasi-allowed" forbidden) K-capture transition to a state with spin I. The neutrino carries away ½ unit of angular momentum, and it is immediately seen that the remaining 1s electron can only be in a state antiparallel to the nuclear spin. This is the consequence of the selection rule ΔF = ± ½. Consequently the observed energy shift is -A(I+1)/2 where A is the usual hyperfine parameter proportional to the nuclear g factor.

Further experiments give evidence for contributions to the energies from shake-off effects in the photo-ionization process and for an effect that reflects the difference in electronic structure between the elements that occur as mother and daughter in the beta-decay process. The effects in the electronic 5d shell are now being investigated and give some evidence for additional and as yet unexplained effects.

6. OUTLOOK AND CONCLUSION

The ISOLDE experiments are right now in a very productive phase and the Collaboration is looking to the coming years with considerable enthousiasm and optimism. This attitude is reflected in our machine time request given in section 7.

Nevertheless, there are in the medium-range future certain technical problems and certain decisions to be taken, that are a cause of concern already now. Without formally proposing a line of action at this moment, we would at least like to bring these considerations to the attention of the PSSC Committee, so that our scientific aims are clear.

6.1 It will require an increased effort to maintain the breadth of ISOLDE's programme.

A number of approved experiments at ISOLDE are progressing much more slowly than the Collaboration would desire. There are essentially three reasons for this : (i) that shortage of manpower and money limits the time, that we can operate, and (ii) that the targets of interest cannot be re-scheduled often enough and (iii) that some targets of interest have not yet been developed. This situation is the natural consequence of the diversity of the programme, and also of our having to devote relatively long time to a few large (key) experiments. It entails, however, that highly qualified small experiments are delayed or abandoned to the detriment of the scientific milieu at ISOLDE. This problem has been discussed in detail in a document from last year ("On the possibility of extending the ISOLDE operations : Physics gains and possible technical solutions", CERN-SCC/78-3/SCC P-2, Febr. 1978), to which we refer, also for suggestions of remedies.

6.2 Protons of higher intensity are an interesting long-term perspective.

We are actively investigating the possibilities of basing an ISOLDE-3 at the SIN meson factory. The preliminary study has considered a facility receiving over long periods a beam of 20 μA with some runs at 100 μA. (It is assumed that the SIN beam at that time will be 1 or 2 mA.) This appears technically possible, both as far as the proton accelerator and as far as target construction are concerned. Safety problems will, however, dictate a somewhat more elaborate set-up than the present one, and optimal operation would also necessitate a larger operations group. We are now trying to find outside help for a more detailed study and costing of the project.

The scientific gains would be mainly in two areas : (i) A more intense proton beam will permit experiments based on target-ion-source systems with smaller yields than those used now, and may extend the range of elements beyond those available today. It also appears probable that new experiments requiring high intensity will be proposed, once it becomes known that the technical possibility exists. An outstanding example is (ii) the study of isospin properties along the N=Z line. In 1977 the first case of a nucleus with $T_Z = -2$ was discovered at CERN, and since, two more cases have been found at Berkeley. Precise experiments on such rare species will require a substantial improvement in intensity.

6.3 Conclusion

The first priority of the Collaboration is to strengthen the operation so that more beam time and a greater variety of secondary beams can be delivered for physics. A facility designed for proton beams of very high intensity clearly offers large potential for the long-term future of the field, but would also necessitate a considerable investment. We would like to underline that the need for proceeding with such a development soon (i.e. in the 2 to 3 years to come) rather than, say

5 years later does not come from ISOLDE or the SC having exhausted their possibilites of progress or development, but rather from an external consideration : CERN's often expressed intent to phase out the SC at the time when the construction of LEP begins.

7. REQUEST FOR BEAM TIME

	Shifts
7.1 With ^{12}C For the experiments proposed by the ISOLDE Collaboration, two periods of one week each in the autumn of 1979. The same in the spring of 1980	40
7.2 With ^{3}He Two runs of 10-15 shifts	25
7.3 With protons About 8 months will be available for this mode. During this period, we would try to operate 30 shifts/month. Full beam will be requested somewhat more frequently than last year (1/3)	240
Total	285

For the ISOLDE Collaboration

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Appendix 1

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Appendix 2

December 1978

On the utilization of the ISOLDE Facility

The number of shifts used for experiments at ISOLDE has this year far exceeded the earlier records and we have during the ten months of operation in 1978 used 227 shifts. The smooth running of the SC and the very reliable and long-lived ISOLDE targets has changed the running so that a typical run now is more than 10 shifts long and we have several times been running around 20-30 shifts. During the same time the number of single users of the beam time has decreased so that the average this year has gone down to 1.5 groups taking data simultaneously. The extension of beam line 3 to UR9 and UR10 and the addition to the experimental floor in UR10 will probably again increase this average in the coming year.

The most important technical development in 1978 was the new $^{3}He^{++}$ beam of 910 MeV from the SC. Several tests and experiments with ^{3}He as bombarding particles have been done and a total of 32 shifts with this beam has been used.

Many experiments have been performed during the year and here I have just picked out three important developments :

(i) The Orsay laser experiments have started, taken large amounts of data (including the identification of the D2 line in Fr) and are almost ready to leave the floor.

(ii) The delayed neutron experiments have started. Much data have been taken on the alkalies Li, Na, K. The prospects for experiments on Rb and Cs are good.

(iii) One of the ISOLDE classics has been successfully completed : the Mainz group have finished their experiments on Hg.

For the next year we look forward to the first ^{12}C beams that will become available in June.

Björn JONSON

ISOLDE Coordinator

Table 1

Operational statistics for ISOLDE

	1977	1978
Number of scheduled shifts	211.5	228.5
Number of shifts used	186	227
Number of user shifts	429	350
Average number of users	2.3	1.5

Table 2

ISOLDE II targets (1975-78)

Target material	Produced activity	Number of shifts	Number of targets used in 1978
UC_2	Fr/Cs/Rb/K/Na/Li	162.5	7
La	Cs	158.5	3
Pb	Hg	140.0	3
Nb	Rb	38.5	2
VC	Ar	38.5	3
Sn	Cd	26.5	1
Ta	Yb/Tm	19.0	
Nb	Kr	10.5	
ScC_2 *	K	10	3
LaC_2	Xe	9	
Au *	Tl(^{3}He)	9	3
Nb	Br	3	
ThC *	Tl(^{3}He)	3	1
Test targets for offline use		-	4
		Total	30

* New target 1978

Number of shifts for experiments at ISOLDE