Particle Accelerators, 1994, Vol. 47, pp. 153–158
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BRAMA, A BROAD RANGE ATOMIC MASS ANALYZER FOR THE ISL*

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(Received 5 July 1993; in final form 30 July 1993)

An alternative to conventional on-line isotope separators for use in radioactive beam facilities is described. It consists of an analyzer with a static magnetic field that is capable of separating a wide mixture of (radioactive) ions into mass bins ranging from 6 to 240u. If incorporated into the ISL, BRAMA would make several low-energy radioactive beams available for experiments *simultaneously*, in addition to the beam that is being delivered to the post-accelerator. A preliminary ion-optical geometry is discussed.

KEY WORDS: Radioactive beams, electromagnetic isotope separation

1 INTRODUCTION

A key component of the IsoSpin Laboratory (ISL) concept is the on-line isotope separator that connects the ion source to the post-accelerator. On-line isotope separation has become a well established tool in nuclear physics, astrophysics and material science since the mid 1960's. Also, during this time the use of radioactive targets and projectiles was mentioned for the first time.[1] Most on-line isotope separators analyze ions from ion sources or He-jet systems with a combination of electric and magnetic fields that are adjusted to the desired isobaric mass chain. In the focal plane of the analyzer a range of ± 10–15% of the center mass is typically available and some on-line isotope separator facilities make use of these side beams for additional experiments. An example is the beam switch yard at ISOLDE/CERN.[2] However, the range of usable masses that is available from a conventional isotope separator is often much smaller than the range of radioactive products that is being produced, in particular when high-energy-spallation- and fragmentation reactions or fission are being used. The out-of-range isotopes typically are implanted in the walls of the vacuum chamber of the separator where they may cause unwanted scattering and long-term contamination. This is a particularly serious problem in the important case of uranium targets. If, for instance, ^{238}U is used to produce light neutron-rich isotopes between He and Ca many of the fission fragments are lost inside the vacuum chamber.

*This work was supported by the Director, Office of Energy Research Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

In its original incarnation and in later versions like the Bench Mark Facility[3] and variations thereof[4] the ISL had an ISOLDE-type isotope separator as its front-end. The most disturbing fact about using this type of isotope separator in conjunction with the ISL is that most of the radioactive isotopes, which are very expensive and cumbersome to produce, are wasted because the narrow range of the separator is poorly matched to the broad-range production mechanisms.

Another point is that many isotopes, particularly near stability, are produced almost independently of the target material, albeit with varying intensities and subject to the mass and charge limitations given by the target and the projectile. This is illustrated in Table 1 for the case of positive surface ionization where it is shown that a large number of light isotopes can be produced with a wide variety of targets. (This example should not detract from the fact that for a given element and isotope there may only be one *optimal* target.) Conversely, Table 1 also illustrates that heavy targets are quite universal in producing a wide variety of elements. These considerations have led to a reevaluation of the method of on-line isotope separation at the ISL, as first reported in Reference 5.

2 THE BROAD RANGE ATOMIC MASS ANALYZER (BRAMA)

It is proposed that the conventional tunable isotope separator be replaced by a Broad Range Atomic Mass Analyzer (BRAMA) with a *fixed* magnetic field that sorts the incoming ion mixture into mass bins in the range of A≈6–240. (The magnetic field should be reversible to allow the analysis of negative ions.) The mass range was chosen to accommodate the lightest RNB of interest (^{6}He) and to permit the mass separation of simple molecules of the heavier elements that may be advantageous for reasons of beam purity.

TABLE 1: Orders of magnitude of radioactive beam intensities (lower estimates) in ions/s of selected isotopes for different target materials obtained from a hypothetical RNB facility as described in Reference 3. Target thicknesses are 1mole/cm^2 and the primary beam is 1-GeV 100μA protons, *no radioactive decay corrections have been applied*, positive surface ionization is assumed, and acceleration- and stripping efficiencies have been included. For further details see Reference 3.

Target isotope	CaO	^{93}Nb	^{139}La	^{181}Ta	^{238}UC
^{8}Li	10^{11}	10^{11}	10^{11}	10^{11}	10^{11}
^{11}Li	10^{7}	10^{7}	10^{8}	10^{8}	10^{8}
^{20}Na	10^{9}	10^{8}	10^{8}	10^{8}	10^{9}
^{30}Na	10^{4}	10^{5}	10^{5}	10^{5}	10^{9}
^{50}K	0	10^{4}	10^{4}	10^{5}	10^{9}
^{97}Rb	0	0	10^{2}	10^{3}	10^{8}
^{111}In	0	0	10^{10}	10^{9}	10^{9}
^{121}Cs	0	0	10^{10}	10^{9}	10^{8}
^{144}Cs	0	0	0	0	10^{9}

A design of a broad-range spectrometer was published by Morgan *et al.*[6] for electrons with momenta of 1–25 MeV/c. Ion optical work on a 1–100 MeV proton spectrometer was reported by Enge.[7] Following this lead, we carried out preliminary calculations of a broad range spectrometer based on a design first published by Borggreen *et al.*[8]

Preliminary choice of basic parameters for BRAMA:

Ion Energy:	100 keV
Maximum Magnetic Rigidity:	0.705Tm
Mass Range:	6–240u
$(B\rho)_{max}/(B\rho)_{min}$:	6.3
Mass Resolution:	$m/\Delta m \gtrapprox 1000$
Dispersion at Mass 240:	$\sim$ 1cm
Sector Angle:	108.7°
Entrance Angle:	35°

A minimum ionic radius of 0.4m for A=6 was chosen, which results in a field of 0.28T and a maximum radius of 2.52m for A=240. The dispersion along the focal plane $\delta s/\delta A$ is calculated to be $0.18A^{-1/2}$ and varies from 7.4 to 1.2 cm for mass 6 to 240, respectively. The ion-optical geometry of BRAMA is shown in Figure 1, and the mass positions and dispersions in Figure 2. The approximate length of the focal plane is 4.7m. The focal plane angle with respect to the field boundary is $\sim$19°.

An important design feature is the beam switch-yard that directs different masses to experiments and the post-accelerator. Figure 1 shows an example of three masses that are selected with *movable* slits in the focal plane. The slits are mechanically attached to electrostatic deflectors that deflect the beams parallel to the focal plane towards the electrostatic distribution deflectors shown to the left. From there the mass-selected beams enter beam lines that lead to the experiments or the post-accelerator. By moving the first deflectors along the focal plane each beam line can be supplied with any mass chain in the range from A=6 to 240u. (Of course, any given mass position can be used only once.) Moving the deflectors parallel to the focal plane does not affect the position of the central rays. It will, however, affect the focusing, which can be corrected with electrostatic focusing elements as shown.

3 OPERATIONAL CONSIDERATIONS

Substituting BRAMA for the conventional on-line isotope separator will significantly enhance the operation of the ISL. This can best be demonstrated by referring to Figure 3, which shows a schematic functional diagram of the ISL front-end. The input to BRAMA can be selected from several target/ion source stations. (These stations may be equipped with

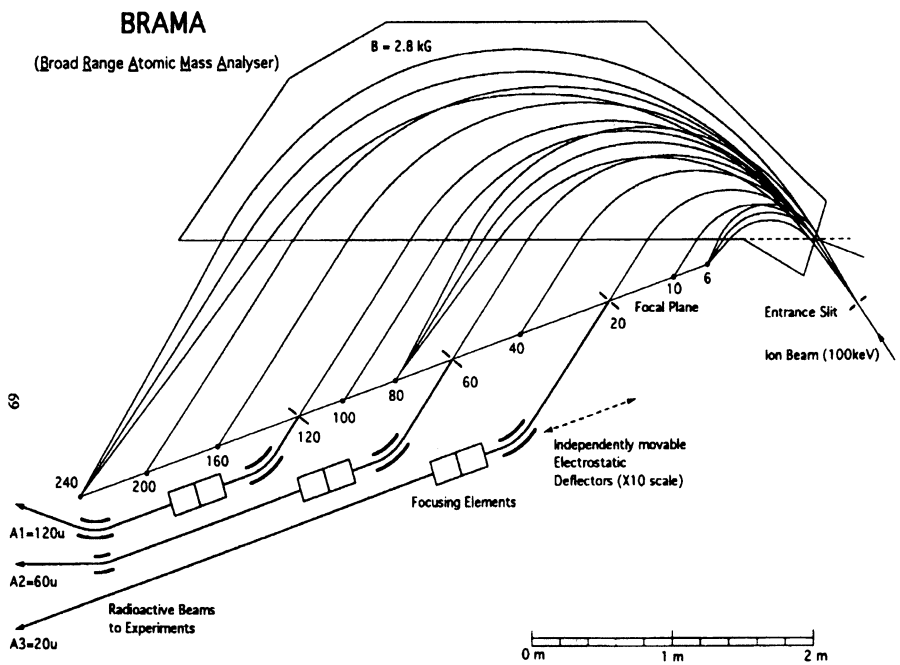

FIGURE 1: Conceptual layout of the Broad Range Atomic Mass Analyser (BRAMA).

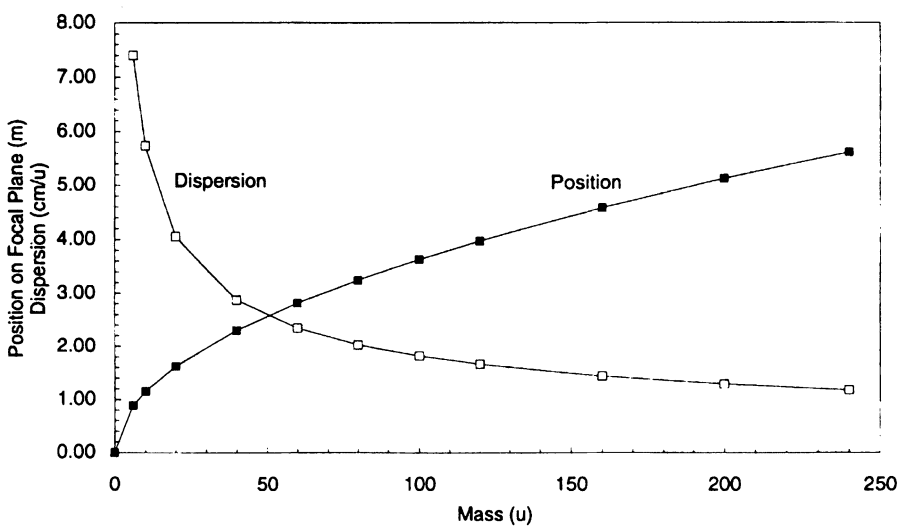

FIGURE 2: Dispersion and position along the focal plane as a function of mass.

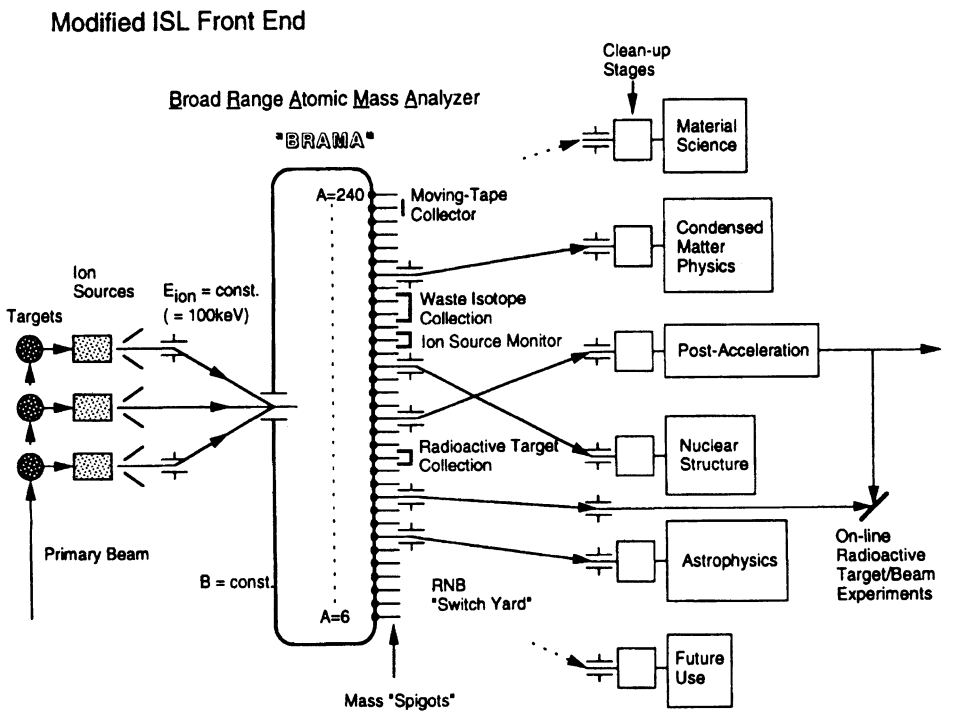

FIGURE 3: Operational diagram of BRAMA.

specialized targets and/or sources that emphasize certain half-life ranges or selectively ionize certain groups of elements.) The mass channels of BRAMA can be considered "spigots" from which all available isotopes can be tapped *simultaneously*. A few examples are shown in the figure.

- The tap with the highest priority is the beam that will be post-accelerated.
- A light-ion beam is made available for astrophysics. (A small dedicated post-accelerator could be added here in the future.)
- Another beam goes to a high voltage platform for condensed matter physics with polarized beams.
- An isotope of the ion-source-support gas could be used to monitor ion source performance.
- A new class of experiments can be carried out where an on-line target is collected and bombarded by an accelerated radioactive (or stable) beam; for example the "cold fusion" reaction $^{130}Sn(^{132}Sn,\gamma)^{262}Fm$ would lead to a new nucleus at the N=162 neutron deformed shell. Or multi-neutron transfer reactions with light neutron-rich beams on radioactive targets could be studied.

- All mass positions not needed for on-line experiments are available to collect isotopes for use as off-line targets or in bio-medical experiments. Long-lived isotopes could be collected for extended periods of time, even from different production targets. They could be chemically purified to remove isobaric contaminants.
- A moving-tape collector could be installed for short-lived activities.
- Very few radioactive ions would strike the wall of the vacuum chamber; mainly tritium and molecules with A>240. (A special "tritium trap" could be installed since the mass-3 beam will always appear at the same position.) Most "waste" isotopes will be collected in the focal plane.

Figure 3 shows "clean-up" stages in front of most experiments since BRAMA will, in general, have insufficient mass resolution ($m/\Delta m \approx 1000$) to resolve isobars. These stages can take different forms, from additional magnetic and electric fields, as in case of the post-accelerator branch, to implantation and re-ionization, and laser techniques. In many cases beam purification may be simplified by a judicious choice of ion sources. If, for example, a uranium target is used together with a negative (LaB_6) ion source mainly halogens will be ionized and radioactive isotopes of different halogens do not overlap in mass and thus, don't cause cross contamination. A particularly favorable situation occurs when laser ionization is used since the "cocktail" of laser wave lengths can be chosen such that only a limited number of isotopes is ionized.

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