Experimental Requirements – Beam and Machine Characteristics

Nigel Orr

LPC-Caen

May 2006 (updated and corrected Nov 2006)

Within the context of the design of the heavy-ion postaccelerator for EURISOL (Task 6) and the overall design of the facility it was requested that the potential user community provide input regarding the desired beam characteristics and related machine parameters etc. This document is a summary of the results of the different discussion sessions organised at the EURISOL Physics workshop in Trento in January 2006 and interactions I have had with individuals before and after the workshop, during the EURISOL week meeting in November 2005 and at the joint meeting of Tasks 6, 9 and 10 in May 2006

The format of this report follows that of the original "questionnaire" (reproduced as an appendix here) that I circulated to members of Task 10 (Physics and Instrumentation) in June and November 2005 and to the Task 6 group at our November 2005 meeting at GANIL. The only major change with respect to the original document is that the issue of sharing the postaccelerator with the β-beams programme is no longer consider an issue as it has since been excluded as an option by the DS steering committee.

The most significant requests with respect to the facility sketched out in the FP5 design study are: an increase of the maximum beam energy to 150 MeV/nucleon (see Item 1); beam sharing based on separate target-ion source-reaccelerator combinations rather than the sharing of the unused charge states of the pilot beam (Item 7); and the need to provide beams with energies below 0.7 MeV/nucleon.

Finally it should be noted that the requests outlined below were made in the context of the "ideal" facility. Whether all of them are technically and/or financially feasible were considered to be outside the remit of the discussions. Those requests which are considered too technically difficult to be implemented will be re-examined at a later date by the Task 10 group. I would, therefore, greatly appreciate any feedback, requests for clarification or specific questions.

1. Maximum Beam Energy

A maximum energy of 150 MeV/nucleon for the benchmark ^{132}Sn beam is requested.

The majority opinion appears to be strongly in favour of such a maximum energy. Whilst far from exhaustive, the motivations include:

- The need to avoid charge-state distribution problems in refragmentation experiments with "heavy beams", the enhanced acceptances generated by such energies and the increased target thickness that could be employed. These issues were considered particularly important for experiments attempting to populate and study the most exotic systems possible in two-step reactions.

- Nucleon "knockout" and similar experiments would benefit greatly for the same reasons and the limit of 150 MeV/nucleon would provide for sufficiently high beam energies for such studies with "heavy" beams (ie., heavier than ^{132}Sn).

- Similarly, reaction dynamics studies would benefit greatly from the increased energy range, in particular by providing for "heavy" beams up to ~70-100 MeV/nucleon.

- Such energies were also required for charge-exchange reaction studies – in particular, to ensure dominance of single-step rather than two-step mechanisms. Comparison with lower energies would also allow different types of transitions to be isolated.

It was also requested that, *if technically feasible*, the high-energy heavy-ion linac should be designed to provide reacceleration without stripping. Given the losses inherent in multiple stripping, such an operating mode would be advantageous when beams of very low intensities (ie., the most exotic species) are employed.

2. Minimum Beam Energy

Beams of energies below 0.7 MeV/nucleon (the lowest energy available from the RFQ in the present design scenario) are required, in particular for the nuclear astrophysics programme.

As such it was decided that a dedicated "low-energy" accelerator (~0-1 MeV/nucleon) would need to be built (see also Item 7, Beam Sharing). Such a device would be considered part of the "instrumentation" for the facility and as such will not fall within the remit of Task 6.

3. Energy Variability

In principle, the finest possible changes in beam energy should be possible. Acceptable upper limits of 0.5% at low energies (<20 MeV/nucleon) and 1 MeV/nucleon at high energies (>20 MeV/nucleon) are deemed to be reasonable.

Fast and precise (see below) beam energy changes were requested for the low-energy beams, especially in the range ~0-5 MeV/nucleon.

4. Beam Energy Definition

Absolute beam energies of 0.1% or better are requested. This issue probably crosses the boundary between the machine and the instrumentation as it requires the implementation of beam-energy analysis spectrometers.

5. Time Resolution

A time width (FWHM) of 0.5 nsec per beam bunch is felt to be highly desirable. An upper limit of 1 nsec is acceptable.

In some instances a bunch width of order 100 psec would be very advantageous. Is this technically feasible? And if so what would be the consequences on the energy spread of the beam?

6. Beam Time Structure: pulse rate and "chopping"

The frequency of 88 MHz (Δt = 12 nsec) currently adopted for the operation of the linac is too high: many experiments will be based on time-of-flight measurements and as such a separation between beam pulses of 100-200 nsec would be required (~5-10 MHz). Presumably this constraint would require the construction of a buncher.

It was noted that for the most intense beams, it would be useful to also retain the possibility to run at a "base" frequency of 88 MHz.

Chopping the beam for periods between 12 nsec – ~1 msec is requested.

7. Beam Sharing

It is strongly recommended that in addition to the dedicated very low-energy reaccelerator (see item 2), low/Coulomb barrier (~1–5 MeV/nucleon) and high-energy (~5–150 MeV/nucleon) reaccelerators/linacs be constructed, each of which would be fed by a *different* target-ion source station.

The principal reasoning behind this philosophy is two-fold:

- The original concept of providing the unused charge states of the pilot beam to the other experimental areas was deemed to have a very limited utility. In particular, the users other than those on the "pilot" experiment would have no choice over the beam energy and isotope supplied to them.

- Many of the experiments at very-low (~0–1 MeV/nucleon) and low/Coulomb barrier energies (~1–5 MeV/nucleon) would be very low-yield (experiments at stellar energies, heavy-element spectroscopy etc) and thus require *very extended running periods* – often several weeks or more. The original beam sharing scheme would mean that no other activities could be carried out with reaccelerated beams during these experiments, essentially paralysing the facility for other users. Such a situation was felt to be unacceptable.

8. Stable Beam Operation

Operation of the postaccelerator(s) with stable beams is requested, with beam intensities up to $10^{12\text{-}13}$ pps (ie., the same intensities as envisaged for the most intense radioactive beams). This request is particularly strong for the high-energy beams. The reasons are:

- Stable beams are essential for setting up and calibrating experimental setups.

- Measurement with stable beams will provide important reference points for studies with exotic beams.

- The production via in-flight fragmentation of elements and isotopes not accessible with EURISOL using ISOL is highly desirable, especially in cases involving the study of a complete series of isobars (or isotopes). Such fragmentation beams will also be important for detector calibrations etc.

- Assuming that the (proton) driver accelerator and target-ion source stations will have non-negligible downtimes, operation of the reaccelerators during these periods will maximise the use of the facility.

- More practically, it was felt that given the ever increasing rationalisation of facilities in Europe and elsewhere, the proposed high-energy reaccelerator would probably be a unique machine circa 2015-20.

9. Beam Purity

Single-isotope beams are preferred in the majority of cases.

The question of whether isobars could be accelerated at the same time was posed. As a corollary, the issue of the acceptance of the linac in A/q was also raised. This possibility, was not, however, felt to be of high priority.

10. Beam Emittance and Spot Size

The most stringent requirements were felt to be at low energies (~0-5 MeV/nucleon) where "tandem-like" beam quality is requested.

While no exact numbers were agreed on, the general consensus was that an emittance of order 2π mm.mrad and a beam spot size of order 2 mm^2 should be aimed for with the minimum possible loses in intensity (ie., such beam quality should not, if at all possible, rely on the use of slits etc). It was recognised that for the very weakest beams it may not be possible to provide such well defined beams.

Appendix: Questionnaire circulated to Task 10 group members

Experimental Requirements – Beam and Machine Characteristics

Nigel Orr

LPC-Caen

June 2005

Within the context of the design of the heavy-ion postaccelerator for EURISOL it is necessary that the potential users provide some input regarding the desired beam parameters etc. This will clearly be an iterative process and eventually compromises and choices will have to be made. I would like to be able to report back to the heavy-ion design group (lead by Marie-Hélène Moscatello, GANIL) on the user community's views regarding a number of major issues that are fundamental to the overall constraints on the design of the post accelerator linac. If you feel that there are other points that need to be addressed please let me know.

1. Maximum Beam Energy

A maximum energy of some 100 MeV/nucleon (for a benchmark beam of ^{132}Sn) was adopted in the preliminary FP5 design study. In many respects the choice of 100 MeV/nucleon is probably a "psychological" one. How imperative is it that such an energy be available?

From a technical point of view such an energy will most probably require various stages of stripping (if the linac is to remain within a reasonable size and budget), with a consequent reduction in beam intensity. If, in terms of a finite budget, a linac *without* stripping was constructed that could deliver beams with a high transmission (ie., increased beam intensity) but with a lower beam energy (say ~60 MeV/nucleon), would that be acceptable? What is the lowest maximum beam energy that is acceptable?

2. Minimum Beam Energy

Ignoring beams directly available following extraction from the target-ion source systems of EURISOL (~100 keV), what is the minimum beam energy required for experiments?

3. Energy Variability

What sort of variability in beam energy is required? This question refers to the beam for a particular experiment, whereby the user may wish to perform a series of measurements at different energies.

Does the variability need to be the same at high, medium and low energies?

4. Beam Energy Precision

How well defined does the beam energy need to be? And how precisely must the absolute beam energy be known?

5. Time Resolution

Many experiments will be based on time-of-flight measurements. In many cases this will be done with reference to the time structure of the beam itself. What time resolution is required (ie., how broad can the individual beam bunches be) ?

6. Beam Sharing

What types of beam sharing should be envisaged between different experiments? Should "parasitic" beam sharing (as at GANIL) be envisaged? If the machine involves stripping should provision be made to use the unused charge state(s) at, say, a "medium energy" beam station?

7. Beam "Chopping"

Experience suggests that some experiments may require the suppression of the beam for a certain period of time and/or number of beam bunches. What sort of capabilities are required? Is there any interest in attempting (if possible) to rebunch rather than simply chop the beam?

8. Stable Beam Operation

What type of stable beam operation should be envisaged? Presumably certain experiments with radioactive beams would ideally be compared to results with stable beams. From a practical point of view experience with SPIRAL shows that calibrations using stable beams (and/or their fragmentation products) are often required. Some type of stable beam operation is also necessary for the tuning of the linac. This would be done at fairly modest intensities (order 10 nAe). Are higher intensities required?

Should very high stable beam intensities (say $10^{12\text{-}13}$ pps) be envisaged? More specifically should it be possible to use the linac to produce radioactive beams by projectile fragmentation; in particular for those cases that are difficult or impossible to produce by ISOL methods ?

As a corollary, should stable beam operation be possible during downtime on the driver accelerator or during dedicated very low-energy experiments?

9. Sharing of Beam time with Beta Beam Operations

At present the possibility is envisaged of using the linac as both a machine for providing the beams for nuclear physics and associated experiments and as an injector into the beta-beams accelerator complex. In this context two distinct options exist:

a). a machine cycle whereby the ^{6}He (or ^{18}Ne) ions are accelerated for say 2 sec, followed by a reconfiguration of the machine settings (~1 sec), and acceleration for say

7 sec of the ion of interest for the nuclear physics experiment. While technically very challenging such a possibility may be technically feasible.

b). a certain fraction of the running time of EURISOL is given over to beta-beam operations and the balance of the time is allocated to nuclear physics etc.

Which of the options is the most preferable?

In either case, a certain fraction of the beam time is given over to the beta-beams programme. What is the *maximum fraction* that acceptable from the point of view of the nuclear physics community? In this context it may be worth keeping in mind that a large scale facility such as EURISOL would most probably operate for at most around 8 months of the year. I understand (to be confirmed) that *a minimum* of some 3 months equivalent beam time would be required by the beta-beams project.