HIGH INTENSITY DRIVER ACCELERATORS FOR EURISOL*

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Abstract

This paper describes briefly the result of the work done by the Driver Accelerator Task Group of the EURISOL RTD project [1]. Accelerator experts from the laboratories participating in this study, namely CEA-Saclay, CERN, GANIL, INFN-Legnaro, IPN-Orsay, have elaborated different technical solutions during the period 2000-2001 [2], following the recommendations for specifications of the EURISOL Steering Committee. The main conclusion of the study is that the EURISOL base-line driver accelerator should be a 1-GeV, 5-MW CW proton facility, with a possible upgrade to 2 GeV. A cheaper "back-up" solution, based on a high-intensity electron driver for photo-fission, is also discussed.

1. INTRODUCTION

The objective of the EURISOL project is the preliminary design study of the next-generation European ISOL facility, aiming at providing radioactive ion beams which are orders of magnitude higher in intensity than are presently available. In the light of this general objective and the inherent limits imposed by practical target considerations, the Steering Committee proposed the following driver options:

- A high-intensity 50-MeV electron accelerator to provide photo-fission products from bremsstrahlung, as the example of a low-cost solution for a dedicated region of the isotopic chart.
- A high-intensity 1-GeV proton accelerator, operated in two intensity regimes: at intensities around a few hundred μA it would be operated as a classical ISOL facility, while the full beam power (around 5 MW) would be used to generate neutrons from a spallation target, which in turn are used for producing fission products (converter method).
- A high-intensity proton accelerator with heavy-ion capability for low-mass species, with ion beam powers of hundreds of kW, because of current interest in some selectively and cross section properties of heavy-ion induced reactions.

The most powerful proton accelerators running at present are the Los Alamos linac and the PSI cyclotron. Beam power is, in both cases, about 1 MW. The inherent energy limitation of the cyclotron and the fact that the ultimate beam power limit is more than an order of magnitude higher for the linac explains why the EURISOL project concentrates on a linac solution. Considering the duty cycle requirements, the maximum smoothing-out of the beam structure is favoured because the power deposited in the radioactivity-releasing ISOL target is a major concern. Moreover, a specific comparative study between pulsed and CW operation has been made [1,2], recommending CW as the preferred mode of operation, assuming that EURISOL would be a stand-alone facility.

2. THE ELECTRON DRIVER OPTION [1,2]

The stated goal for a EURISOL electron driver is to induce more than 10^{15} fissions/s in the uranium target. This goal leads to beam specifications as follows: final beam energy 50–70 MeV; average beam current 20–30 mA. In order to create this 1 to 2-MW electron beam, a high power CW superconducting electron linac was considered, so as to benefit from the inherent advantages of SCRF cavities: optimal efficiency, reduced overall length, reduced activation, flexibility and reliability.

2.1 General Layout

The proposed layout of this electron linac is very simple (see Fig. 1): an injector, composed of an electron gun followed by a capture cavity, accelerates the beam up to about 5 MeV; a subsequent β=1 section increases the energy to 50 MeV at least. The overall length of such a machine is about 20 metres.

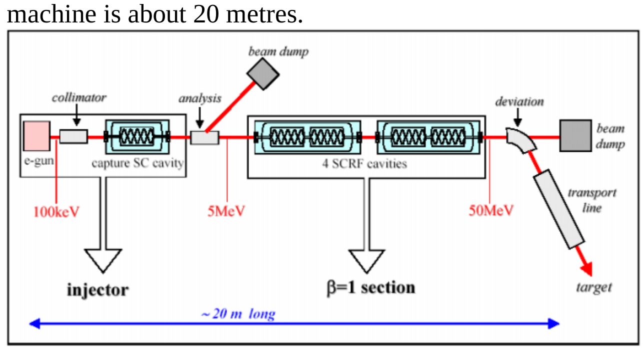

Figure 1: Layout of the EURISOL electron linac.

2.2 The injector

The injector is composed of a 100-keV high current electron gun (e.g. a gridded triode with modulation of the cathode for bunching), a collimator system to control the beam emittance, and a capture cavity to accelerate the beam up to a few MeV with large energy and phase acceptance. A preliminary design of such a capture cavity has been achieved in both Spiral-II [3] and EURISOL contexts: two 5-cell prototypes have been designed, the first being a 5-cell β=0.85 cavity, the second being a "hybrid" cavity composed of two β=0.8 cells followed by three β=1 cells. Simulations have been done considering an operation with a conservative value of the peak surface

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magnetic field (B_{pk}=50 mT, corresponding to E_{acc}≈12 MV/m). For both cavities, the output energy exceeds 4.5 MeV, the phase acceptance before capture is comfortably large (about 90°), and the bunching properties are very good (less than 5° phase dispersion at the cavity exit).

2.3 The β=1 section

The β=1 section is composed of only 4 superconducting cavities in a single cryomodule; the energy gain needed to reach 50 MeV is thus about 11.5 MeV per cavity. It can be shown that this goal can easily be achieved while operating at very safe values of the peak surface fields, leaving margins for a possible energy upgrade up to 70 MeV. A major consideration here is the very high RF power needed in each cavity, between 200 and 500 kW CW depending on the final energy (50–70 MeV), and the beam current (20–30 mA). The most important point is the impact on the power coupler: even if recent advances have been performed in several laboratories (KEK, Los Alamos, CERN…), the development of such a high power coupler remains a real technological challenge. An alternative would be to increase the number of cavities.

2.4 Elements for the frequency choice

In order to benefit from the ongoing developments on other projects, three possible frequencies have been considered: 350 MHz (CERN-LEP), 700 MHz (European proton drivers, APT/AAA) and 1.3 GHz (TESLA/TTF). It appears that better efficiency and shorter length are reached operating at 700 MHz or at 1.3 GHz. However, availability of equipment at 350 MHz due to the development of this technology for LEP could outweigh balance the intrinsic drawbacks of such a low frequency.

2.5 Preliminary cost estimate

A preliminary cost estimate has been made for a 50-MeV, 20-mA electron driver running at a frequency of 700 MHz, which can be upgraded to 70-MeV, 30-mA. The estimated overall investment (see Table 1) is about 20 M€, buildings included – 15 M€ without. The electricity cost should not exceed 1.5 M€/year for an 80% operation time.

Table 1: Estimated investment cost for the electron driver (contingencies included, manpower not included)

Cryomodules	3.4 M€
Injector	1.4 M€
RF Sources (IOT)	4.1 M€
Cryogenics	5.4 M€
Other (Control System, Vacuum…)	0.5 M€
TOTAL Component Cost	**14.8 M€**
Infrastructures (for test and assembling)	1.4 M€
Buildings	4.2 M€
TOTAL Investment Cost	**20.4 M€**

3. THE BASE-LINE PROTON DRIVER [1,2]

A 5-MW proton driver accelerator is proposed as the base-line solution for producing both neutron-deficient and neutron-rich exotic nuclei far from the valley of stability. The general layout of such a proton driver (see Fig. 2) is quite well-established, thanks to the numerous existing projects based on this kind of high power linear accelerators. It is composed of three main parts: the low energy section (up to 5 MeV), the intermediate section (up to 85 MeV) and the superconducting high energy section (up to 1 GeV, with a possible upgrade to 2 GeV).

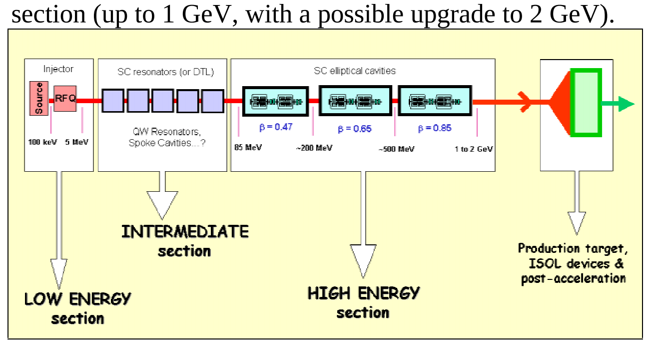

Figure 2: Layout of the EURISOL proton linac.

3.1 The low energy section

A room-temperature copper RFQ structure fed by a high intensity ion source has been adopted for the injector of the EURISOL proton driver. As a matter of fact, several laboratories are presently making huge R&D and construction efforts for such accelerators which aim at ultimate intensities well above the EURISOL demand. The Los Alamos National Laboratory was the first to operate such an accelerator, LEDA, at intensities of the level of 100 mA CW. In Europe, INFN is building an injector in Italy within the TRASCO programme, while in France, the IPHI project is composed of an ECR source, routinely delivering a 95-keV 100-mA proton beam, followed by a 352-MHz 5-MeV RFQ presently under construction. In the three cases, very good performances have been achieved, that fully demonstrates the feasibility of a 5-MeV 5-mA CW proton injector for EURISOL.

3.2 The intermediate section

For this range of energy (5–85 MeV), two solutions with the same frequency (352 MHz) have been discussed: a room-temperature solution, based on a DTL structure, and a cold solution, using superconducting resonators. Comparing the two options, it appears that the investment cost and the overall length for both solutions seem to be of the same order (20–25 M€, 60–80 m). On the other hand, the AC power difference between the two options is very large (about 7 MW) and makes a huge difference in the operating cost, in the order of 2 M€/year. Moreover, the superconducting option gives higher safety (larger beam tubes), and has great potential in terms of reliability and flexibility thanks to its independently phased structures, allowing for example heavy ion acceleration. As a consequence, the EURISOL intermediate section will use, a priori, superconducting cavities. Two different designs have been proposed by LNL [4] and IPNO [5], the first using half-wave and 4-gap ladder resonators, the second using 2-gap spoke cavities; in both cases, the total number of cavities is around 90. The construction and test of the first spoke and QWR prototypes have recently been launched in Europe, but it is clear that this very promising but rather new technology still needs much important R&D effort for demonstration. The “warm” DTL solution, while less attractive from the point of view of efficiency, cost and flexibility, still exists as a back-up solution.

3.3 The high energy section

The proposed superconducting linac for the high energy section of the proton EURISOL driver is inspired from an original study from the ASH (France) [6] and TRASCO (Italy) projects [4], leading to a common design for an ADS driver. This design is based on the use of elliptical superconducting cavities operating at a frequency of 704 MHz, to take advantages of the successful technological progress made in the field of multi-cell niobium cavities. The general layout of the EURISOL high energy section has been settled using all the optimisation criteria developed by the French-Italian collaboration for the cavities, the linac design and the beam dynamics studies: 5-cell, β=0.47 cavities are used from 85 MeV to 190 MeV (2 cavities/module), followed by 5-cell, β=0.65 cavities up to 480 MeV (3 cav./module), while 5-cell, β=0.85 cavities (4 cav./module) cover the high energy end up to 1 GeV (or 2 GeV). The total number of cavities is 134 (234 for 2 GeV), and the overall length is 270 m (475 m for 2 GeV). In parallel, a huge R&D program has started both in France and Italy [6,7,8], with the construction and test of the first prototypes of such low-β elliptical SCRF cavities, showing performances well above the design point. In this context, the construction of full-scale prototypes of cryomodules for the β-values required is envisaged.

3.4 Preliminary cost estimate

A preliminary cost estimate has been made for a 1-GeV, 5-mA proton driver. The estimated overall investment (see Table 2) is about 120 M€ without buildings. The total AC power needed is about 15 MW, and the electricity cost should not exceed 6 M€/year for an 80% operation time.

Table 2: Estimated investment cost for the 5-MW proton driver (buildings & manpower not included)

Injector	8 M€
Intermediate section (Cryomodules)	13 M€
Intermediate section (RF system, others)	7 M€
High energy section (Cryomodules)	31 M€
High energy section (RF system, others)	35 M€
Cryogenic System (5 kW, 2 K)	26 M€
TOTAL Component Cost	**120 M€**
2 GeV upgrade	*+ 65 M€*

4. HEAVY ION CAPABILITY

In order to be able to accelerate some heavy ions in the EURISOL proton driver described in the previous section, two basic specifications have been taken in account: the number of gaps per accelerating structure has to be kept small, and the phase in the successive accelerating structures has to be independently controlled so as to provide a large velocity acceptance. These requirements in particular show that the development of a superconducting version for the intermediate section is crucial if one wants to accelerate both heavy ions and protons. Different heavy ion capability scenarios have been identified within the EURISOL study [1,2]; the conclusion is that, owing to the principle of independent phasing and some margin in the maximum surface fields of the elliptical cavities, acceleration of A/q=2 ions is potentially feasible up to 500 MeV/u, for an additional investment (construction of a dedicated 5-MeV injector twice as long) of at least 35 M€. Acceleration of A/q=3 ions would need significant modifications in the linac architecture, and would imply increased additional costs which have not been fully investigated yet.

5. CONCLUSION

- The EURISOL base-line driver accelerator, a 1-GeV, 5-MW CW proton facility has been investigated in some detail. The cost estimate for this accelerator is 120 M€, not including buildings and contingencies.
- This proposed solution has remarkable synergies in components and R&D needs with other high-intensity projects, and is thus in the mainstream of today’s accelerator development. The demonstration of the injector accelerator relies on existing projects (IPHI & TRASCO), but two items have high R&D priority: (a) construction of complete prototype accelerator sections for low-β elliptical SCRF cavities; (b) development of prototypes of spoke, half-wave and ladder cavities with associated RF components.
- As a driver for fission-products only, and for neutron fluxes below 10^{17} n/s in the target [1,2], the electron driver option is an interesting and somewhat cheaper back-up solution (20 M€ buildings included).

6. REFERENCES

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