EUROPEAN COMMISSION CONTRACT No. HPRI-CT-1999-50001

THE EURISOL REPORT

A FEASIBILITY STUDY FOR A

EUROPEAN ISOTOPE-SEPARATION-ON-LINE

RADIOACTIVE ION BEAM FACILITY

December 2003

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Co-ordinated by Prof. Jean Vervier

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CERN-ISOLDE: European Organization for Nuclear Research - Isotope Separator On-Line
CLRC: Council for the Central Laboratory of the Research Councils
CUT: Chalmers University of Technology
GANIL: Grand Accélérateur National d'Ions Lourds
GSI: Gesellschaft für Schwerionenforschung
INFN-LNL: Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali di legnaro
IPN: Institute de Physique Nucléaire
JYFL: Accelerator Laboratory, University of Jyväskylä
KU Leuven: Katholieke Universiteit Leuven
NuPECC: Nuclear Physics European Collaboration Committee
UCL: Université Catholique de Louvain

Contents

The reports of the EURISOL Task Groups are bound separately as Appendices:

Executive Summary

The present report includes a synthesis of the work carried out within the EURISOL contract – funded by the European Commission – by ten major European Nuclear Physics laboratories. The detailed results of this work are contained in the reports of the five Task Groups, in Appendices A to E.

The EURISOL project aims at a preliminary design study of the 'next-generation' European Isotope Separation On-Line (ISOL) Radioactive Ion Beam (RIB) facility, which will extend and amplify, beyond the year 2010, the exciting work presently being carried out at the first-generation RIB facilities in Europe and other parts of the world, in the fields of Nuclear Physics, Nuclear Astrophysics and Fundamental Interactions.

In this document, the scientific case for high-intensity RIBs using the ISOL method is first summarised, more details being given in Appendix A. It includes (a) the study of atomic nuclei under extreme and so-far unexplored conditions of composition (i.e. as a function of the numbers of protons and neutrons, or the so-called isospin), rotational angular velocity (or spin), density and temperature; (b) the investigation of the nucleosynthesis of heavy elements in the Universe, an important part of Nuclear Astrophysics; (c) a study of the properties of the fundamental interactions which govern the properties of the Universe, and in particular of the violation of some of their symmetries; (d) potential applications of RIBs in Solid-State Physics and in Nuclear Medicine, for example, where completely new fields could be opened up by the availability of high-intensity RIBs produced by the ISOL method.

The 2 methods for production of RIBs, i.e. the ISOL and In-Flight methods, are also described, their complementarity is underlined and the present world-wide situation with respect to RIB facilities, including the short-term projects, is presented. This points towards the need for 'next-generation' infrastructures such as the proposed EURISOL facility, with intensities several orders of magnitude higher than those presently available or planned

The proposed EURISOL facility is then presented, with particular emphasis on its main components: the driver accelerator, the target/ion-source assembly, the mass-selection system and post-accelerator, and the required scientific instrumentation. Specific details of these components are given in Appendices B to E, respectively.

The driver accelerator investigated in this study is a 1-GeV, multi-MW, superconducting proton linear accelerator, although the implications of enabling it to accelerate light heavy ions with charge-to-mass ratios of 1/2 and 1/3 were also considered. An alternative suggestion – i.e. an electron accelerator using brehmsstrahlung to generate photofission – was also examined, but found to have limitations which would make it more expensive for the high yields demanded for EURISOL.

The proposed ISOL facility would use both (a) 100-kW proton beams on a thick solid target to produce RIBs directly, and (b) a 'converter' target to release high fluxes of spallation neutrons which would then produce RIBs by fission in a secondary target. The third method envisaged (c) is similar in concept, but would use a 1–5-MW proton beam on a windowless liquid mercury-jet 'converter' target to generate the neutrons.

The predictions for the expected yields from EURISOL are outlined, as obtained using the best presently-available methods to determine the various factors which will influence the performance. We conclude that the proposed facility will produce beams of radioactive ions with yields which will be one to three orders of magnitude – depending on the nucleus involved – higher than presently available RIBs, and that many hitherto completely unexplored regions of the Chart of the Nuclei will thus become accessible. Typical key experiments within the general scientific fields outlined above, which will then be made possible, are presented as 'boxes'.

A number of different options for the post-accelerator were studied, and the preferred solution is again a linear accelerator, capable of accelerating the RIBs with very low loss to 100 *A* MeV, up to at least ^{132}Sn, for example. At this energy, secondary fragmentation can be done with such neutron-rich nuclei, leading to production of very neutron-rich nuclei that cannot be produced by more conventional single-step processes. Important multi-user considerations are the provision of several simultaneous beams from the mass-separator, the extremely wide range of energies available from the post-accelerator, and the ability to switch post-accelerated RIBs to different experimental areas from successive sections of the post-accelerator.

Before the full engineering design of the proposed EURISOL facility can be performed, Research and Technical Developments (RTD) on some crucial technical points have to be carried out. These have been identified during the course of the present contract, and are detailed in Appendices B to E for the various components of the facility outlined above, and they are also summarised in the present report. Similarly, the possible synergies of EURISOL with other major projects of European scientific communities, both at the level of RTDs and of the possible sharing of some parts of EURISOL with these major projects, have been identified in Appendices A to E and are summarised in the present report. Of particular interest is the possible use of the EURISOL driver accelerator to produce RIBs which then decay to produce neutrino beams with excellent properties – so-called 'beta beams'. This aspect creates unique opportunities for collaboration between the Nuclear Physics and Particle Physics communities. Another interesting spin-off is the ready availability at EURISOL of high yields of new medical radioisotopes which are at present either available only in very small quantities or not at all.

The estimates of the costs of EURISOL, construction and running costs, have been performed in as much details as is presently possible, with some remaining uncertainties. These have been carried out for the various components of the facility, as outlined in Appendices B to E, and are summarised in the present report, together with some additional cost estimates. The total capital cost of the project is estimated to be of the order of 613 M€, within 20%, as outlined in the body of this report. This sum, while large, is not extravagant when compared to the cost of other large-scale national and multi-national facilities. It is important to emphasise that the EURISOL facility would be a European research facility, and would be intended to serve as a hub for a wide multi-national, multi-user community within and beyond Europe.

We are of the opinion that the present phase of the EURISOL project should be followed by two other phases: a number of RTD investigations on the crucial technical points identified as outlined above – perhaps as a Design Study – leading to a full engineering design of the proposed facility. If successful, these two phases would lead to the construction, beyond the year 2010, of a major European Radioactive Ion Beam ISOL facility for the advance of Nuclear Physics, Nuclear Astrophysics and Fundamental Interactions. This will maintain Europe's pioneering position in these fields where many European scientists have in the past played a leading world-wide role.

1 Introduction

1.1 Radioactive ion beams

Nuclear physics – originally a subject of purely experimental and academic interest – has led to untold applications and spin-offs in modern times. Medical technology springs to mind, with radioactive isotopes being used for diagnostic and therapeutic purposes, while particle accelerators are now used routinely for radiotherapy. However, the impact on other fields is enormous, encompassing such disparate fields as power generation, microchip technology, space research and astrophysics. The search for a better understanding of nuclei, and even of the way that matter is synthesised in the Universe, all depend crucially on our knowledge of the physics of the nucleus.

Basic nuclear physics research is delving ever deeper into the unknown, to measure and explain the behaviour of nuclei, and is now reaching out to determine the properties of exotic nuclei, beyond the realm of the stable nuclei, even reaching the 'drip-lines' at the very edge of the nuclear chart. New modes of nuclear decay have been recently observed, while tests of fundamental symmetries, testing and refinement of the Standard Model of fundamental interactions, and exploration of the 'magic' numbers of protons and nuclei in such exotic nuclei are all enticing avenues of discovery.

The study of these radioactive nuclei, involved as they are in nucleosynthesis in the stars and in supernovae, leading to the creation of the very stuff we are made of, has until now been prohibited by their very short lifetimes and the limited yields produced with our present medium-energy accelerators. By using current technology, we are now able to produce accelerators and ingenious systems for producing beams of radioactive ions in quantities which will permit their properties to be measured and understood. The quest for radioactive ion beams (RIBs) which are orders of magnitude more intense than those currently available is the motivation behind the exciting EURISOL project.

1.2 Aim of the project

The EURISOL project aims at a preliminary design study of the 'next-generation' European Isotope Separation On-Line (ISOL)* Radioactive Ion Beam (RIB) facility. The latter will extend and amplify, beyond the year 2010, the exciting work presently being carried out at the first generation RIB facilities, in Europe and all over the world, in the fields of Nuclear Physics, Nuclear Astrophysics and Fundamental Interactions.

1.3 Background to the project

The EURISOL programme finds its origin in the work of the **Nuclear Physics European Collaboration Committee (NuPECC)**, an expert committee of the European Science Foundation (ESF). In 1997, NuPECC issued a report entitled: ***'Nuclear Physics in Europe: Highlights and Opportunities'*** [1]. In addition to a thorough review, in a European perspective, of the recent achievements and future challenges of Nuclear Physics, the report

* The two ways of producing Radioactive Ion Beams (RIBs), i.e. the Isotope Separation On-Line (ISOL) method and the In-Flight method, are thoroughly described in sub-section 3.1.

includes recommendations, one of which reads as follows: "A study group should be set up in order to investigate the main options for second-generation radioactive ion beam facilities in Europe".

Following this recommendation, a RNB Study Group* was established in 1997, whose work extended over about 2 years, and was summarised in a report entitled ***'Radioactive Nuclear Beam Facilities'*** [2] issued in 2000.

To give a wider global perspective, a Nuclear Physics Working Group, created by the Megascience Forum of the Organisation for Economical Co-operation and Development (OECD), issued a report in 1999 entitled: ***'The OECD Megascience Forum - Report of the Working Group on Nuclear Physics'*** [3].

One of the recommendations it contains reads as follows: "The Working Group recognises the importance of radioactive nuclear beam (RNB) facilities for a broad programme of research in fundamental nuclear physics and astrophysics, as well as applications of nuclear science. A new generation of high-intensity RNB facilities of each of the two basic types, ISOL and In-Flight, should be built on a regional basis. Interested governments are encouraged to undertake the necessary decisions within the next few years, and the facilities themselves should become operational in five to ten years".

The first concrete application of these recommendations in Europe was the launch of a proposal for a major upgrade of the facilities available at the Gesellschaft für Schwere Ionen Forschung (GSI) in Darmstadt, Germany [4,5], recently approved by the German Government. One of the major scientific goals of this 'International Accelerator Facility' at GSI is the production of very intense RIBs by the In-Flight method. When operational, this facility will be the 'next-generation' European In-Flight facility recommended by the OECD Working Group.

The second application of these recommendations, i.e. the first step towards the construction, in Europe, of a next-generation RIB facility based on the ISOL method, is the EURISOL programme, whose general aim is defined at the beginning of this section. This programme started on January 1, 2000, and is supported by the European Commission (EC) under the Research and Technical Development (RTD) contract number HPRI-CT-1999-50001. The present report describes the results obtained within this programme during its 4 years of work (2000–2003).

1.4 Methodology

The EURISOL Steering Committee, which included representatives of each of the participating institutions, identified the following five tasks:

- **Task 1:** The identification of **key experiments** which will be carried out with the planned facility, and of their specific technical needs in terms of the nature, energy and intensity of the required RIBs.
- **Task 2:** The definition of the **driver accelerator** for providing the accelerated particle beams which will produce the radioactive nuclei of interest.
- **Task 3:** The specifications of the **targets & ion-sources** required, where the impact of the beams from the driver accelerator will produce the radioactive species, and where the latter will be transformed into ions.

*Note: The term 'Radioactive Nuclear Beam' – abbreviated to RNB – is often used instead of the somewhat more accurate 'Radioactive Ion Beam' or RIB.

❖ **Task 4:** The definition of the **mass-separator and post-accelerator** systems, with which the radioactive ions will be selected according to their masses and accelerated to the required final energies.

❖ **Task 5:** The identification of the scientific **instrumentation**, experimental apparatus, electronics, etc., which will be required to carry out the key experiments with the RIBs produced.

Five Task Groups were formed to carry out these particular tasks, and the results of their work are thoroughly described in the accompanying Appendices. (We note in passing that some of these reports were essentially complete by the end of 2002, while others needed more time for completion. As a consequence, some recent developments might not be referred to.)

The present report presents an overview which synthesises their work, and includes:

- a description of the scientific need for high-intensity RIB facilities;
- the case for the EURISOL facility;
- a general presentation of the proposed facility;
- its expected performance;
- a few key experiments illustrating the need for EURISOL;
- the R&D which will have to be carried out before the full engineering design of EURISOL can start;
- possible synergies between such a facility and other major European projects;
- cost estimates for the facility; and
- the conclusions drawn from this study.

During the course of the present programme, NuPECC launched the elaboration of a **Long-Range Plan for Nuclear Physics in Europe**, based on and updating the previous report *'Nuclear Physics in Europe: Highlights and Opportunities'* [1]. The conclusions of this work reinforce those of the previous report, particularly where it concerns the next-generation European ISOL RIB facility, i.e. EURISOL. The report on this long-range plan is presently being edited by NuPECC.

The present first phase of the EURISOL programme, carried out within the Fifth Framework Programme (FP5) of the European Commission (EC), should be followed by two other phases:

(1) The completion of R&D studies on some crucial technical points which have been identified during the present phase, to be carried out within the EC's Sixth Framework Programme (FP6) under a **Design Study** contract;

(2) A full **engineering design study** of the facility, to be performed within the Seventh Framework Programme (FP7).

At some stage during this process, a suitable site should be chosen (presumably at an existing large accelerator facility, after which the **construction phase** of EURISOL could start, leading to the full **operational phase** after the year 2010.