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The European Spallation Source Project and Nuclear Waste Transmutation

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Introduction

WISE-Paris was commissioned by various German, Danish and Swedish organisations[1] to produce a memo on the European Spallation Source (ESS) Project. The timeframe and budget did, of course, not allow for an in-depth analysis of the coherence and implications of a complex technical 1.5 billion euro project involving several countries and, potentially, hundreds of scientists.

However, a preliminary analysis raises a number of questions that do not find appropriate answers in the present state of the project's definition.

One example is the conflicting history and nature of the ESS project when it comes to potential research and development of transmutation of long lived nuclear wastes.

The present memo briefly looks at the history of the project and at its possible role in the framework of EU research. This is by no means a comprehensive evaluation. The authors of the present document estimate that it would be of primary importance to carry out an independent in-depth assessment of the justification, long term orientation, social benefit and cost of the project for the host country and the EU before taking any decision on the viability of the initiative.

I. The European Spallation Source Project

I.A. Nature of the Project

I.A.1 Actors of the ESS Project

Based on a joint initiative from the Forschungszentrum Jülich (DE) and the Rutherford Appleton Laboratory (UK) in 1991 and 1992 on next generation neutron sources, the European Spallation Source (ESS) project started in 1993 with the establishment of the ESS Council[2], bringing together representatives of research institutes mainly from Europe (ESS main partners are listed in Annex 1).

Considering the composition of the ESS Council, it is clear that the project is primarily a European project gathering European researchers' interests, with the collaboration of countries involved in neutron scattering facilities of the ESS type.

I.A.2 Technical Points on the ESS

There are potentially two types of neutron scattering facilities: Those based on high neutron flux reactor technology (i.e. like fast breeders), or those based on Linear Accelerator (LINAC) technology with an added spallation target. Both types provide a high flux of neutrons, captured and guided toward instrumentation needed for different types of research, from medical applications or fundamental physics to transmutation applications. Linear accelerators produce more easily pulsed

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[1] In Denmark The Ecological Council and The Danish BARSEBÄCKSOFFENSIV that consists of NOAH – Friends of the Earth, Eco-net, The Danish Society for the Conservation of Nature, Nature and Youth, The Danish Organisation for Renewable Energy, The Ecological Council and Enhedslisten and in Sweden the Swedish BARSEBÄCKSOFFENSIV and Folkkampanjen mot Kärnkraft/Kärnvapen.

[2] The ESS Council brings together the "shareholders" of ESS. Its chairman is Dr. Peter Tindemans, from the Netherlands, a former chairman of the OECD Megascience Forum, "*a physicist by education, with a strong political background and close ties to politics and European Organisations*", according to the ESS web site (See http://www.ess-europe.de/ess_js/description.html).

beams of neutrons, but some high flux reactors also provide a pulsed mode. However, spallation based facilities are more efficient than reactors for the production of high energy neutrons. Moreover, safety concepts are totally different because of the different types and quantities of nuclear materials used. Linear accelerators use passive safety concepts whilst high flux reactors are bound to safety concerns comparable with nuclear power stations.

In the case of the linear accelerator based design, protons are accelerated along the accelerator and potentially a synchrotron, they are then selected and sent to accumulation rings and are finally then projected onto targets. Collisions between the protons and atoms of the target material produce neutrons (i.e. spallation). The neutrons flux are then canalized through tubes toward instrumentation. In the high flux reactor case, the neutrons come directly from the fission reaction and are canalized by reflectors toward the instrumentation.

The ESS is based on one of the most powerful linear accelerators in the world, developing 1,334 MeV (MegaElectronVolts), compared with the current 70 MeV UK ISIS linear accelerator (coupled with a synchrotron accelerating particles to 800 MeV) or the 590 MeV SINQ linear accelerator. However, the US SNS (Spallation Neutron Source) project includes a 1,300 MeV linear accelerator, which is scheduled to come into operationaround 2005-2006, and the KEK-JAERI J-PARC project (Japan Proton Accelerator Research Complex) is designed with 3,000 MeV and 50,000 MeV linear accelerators in mind. J-PARC is scheduled to operate as soon as 2005 (for the first linear accelerator; 2007 for the second). One should note that the **Japanese** project includes **specifically waste transmutation** research and applications in the main proclaimed purpose of the facility.

The ESS project thus is **far from being a unique project** in the world nor is it the most powerful. It is beyond the scope of the present memo to analyze in what respect these various projects are **competing** with each other, what is the potential overall **research "market"** and what would be the **potential justification** for each of the facilities. These questions **should be evaluated** in an investigation of appropriate scale.

Concerning transmutation applications, a 1996 paper[3] by C.S. Bauer of the ESS-study team is clear on the capability of ESS to conduct transmutation experiments, concluding explicitly that "*further [ESS] development, construction and operation will therefore not only provide condensed matter science with an unprecedented tool, it will also mark* ***an important milestone in the endeavors to develop the new technology of accelerator driven transmutation devices and power generation facilities****.*"[4] It is also specified that although ESS feature "*pose special requirements to the design, many of the main parameters of the project can be considered as prototypical for an ADTT*[5]*-facility*".

I.A.3 Cost Elements

Between the first and the second ESS study, global costs have greatly escalated, as the following table shows:

	Construction costs (million euros)	Operation cost (million euros per year)
First ESS study (November 1996)	900 (+/- 20%, no allowance for contingency)	85
Second ESS study (May 2002)	1,552 (15% contingency included)	142

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[3] "*The European Spallation Source Study, ESS*", G.S.Bauer, Proceedings of the second International conference on Accelerator-Driven Transmutation Technologies and Applications, Kalmar, Sweden, 3-7 June 1996.

[4] We underline.

[5] Accelerator-driven transmutation and technologies

In order to explain this escalation, the last ESS study (2002) specifies that *"The cost estimates are based on the extrapolation to 10 MW of the updated ESS Vol. III (1996), bottom up estimates of the current ESS design and additionally involving industrial expertise."*[6] The cost estimates are also evaluated considering the evolution of the US SNS (Spallation Neutron Source) facility under construction.

It is however somewhat disturbing that **the latest ESS study of May 2002 does not detail the costs as precisely as the early 1996 study did**. Only a global evaluation of the cost is given, where the 1996 study describes an array of anticipated expenses.

Moreover, the development costs are not even mentioned in the 2002 study; useful information on the evolution of the project could have been provided. It is only specified on the ESS web site that "the costs during the proposal preparation phase until middle of 2003 are expected to be covered by annual contributions of the 18 MoU [Memorandum of Understanding] partners and by EU funding."[7] In 1996, more than 36 million euros were forecast to be spent on three years of research and development (1997-2000). No information is available concerning the amount of funding expected from the European Union, for the construction costs as well as for the operational costs; EU funding will nevertheless determine the future of ESS.

Concerning the cost components, the following repartition has been estimated as follows[8]:

Phase	General	Additional contributions
Construction (planned for 2005-2011)	80 to 85 % of the construction costs are expected to be distributed among participating nations using a formula to be negotiated in the Convention	An additional contribution of between 15 to 20 % of the construction costs is expected to be a site premium for the host country.
Operation (beyond 2012)	95 to 98 % of the operation costs is expected to be distributed among participating nations using a formula to be negotiated in the Convention	An additional contribution between 2 to 5 % of the operation costs is expected to be a site premium for the host country.

The decision on the site and the funding of ESS is expected to be made in late 2003/early 2004 by the ministers for science and research of the participating European countries.

Considering the expected employment, it has been announced that 650 jobs are to be created for 2020 (244 scientists/engineers, 316 administrative & technical staff, 40 post-docs, 50 students; not included are firemen, security guards, medical support). According to ESS data, ESS facilities are likely to be used by a community of about 4,000 researchers.

It is interesting to notice that a significant part of ESS operation costs are devoted to paying for the electricity consumption of the facility : according to the German Science Council[9], those electricity costs are estimated to be 44 million euros (2001 estimate for 100MW power consumption of 10MW linac). Considering that the annual operating time is estimated to be about 200 days, the expected electricity cost of the facility is more than 9,000 euros per operating hour.

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[6] ESS Vol. III (2002), Chapter 9-10.

[7] See the *homepage for candidate ESS Sites* : http://essnts.ess.kfa-juelich.de/site/info/.

[8] "*Info for candidate ESS sites concerning the site document preparation*", European Conference: ESS – European Source of Science, Bonn, 16–17 May 2002.

[9] Wissenschaftsrat in its ESS assessment, 12 July 2002, p.33. On Internet : http://www.wissenschaftsrat.de/texte/5373-02.pdf.

With an annual operating time of 200 days and a 100MW power consuption, the total electricity consumption of ESS is about 480 GWh a year ($4.8*10^8$ kWh/year). The average electricity consumption in Denmark is about 6.48 MWh per capita[10] (not only for household consumption, but also including industrial consumption). Therefore, the electricity consumption of ESS is equivalent to that of a Danish city of more than 74,000 inhabitants, i.e. more than 1.7 times the electricity consumption of the city of Roskilde, and approximately that of a city like Esbjerg.

To compare with Swedish data, the same calculation gives a consumption equivalent to that of a city of more than 30,000 inhabitants (the Swedish average electricity consumption is far higher than the Danish one, being about 15.66 MWh per capita[11]), as big as the city of Lidingo.

These numbers are a conservative estimate, as the real power consumption of ESS could be as high as 150 MW, as specified in ESS document "*Guideline on how to submit an expression of interest to host the European Spallation Source*"[12] of November 2001[13].

I.B. History of the Project

The ESS Project is initially based on an initiative from the Forschungszentrum Jülich (Germany) and the Rutherford Appleton Laboratory (UK), in 1991-1992. The ESS Council was created in 1993, initiating a 3-year feasibility study led by the partner laboratories and partially funded by the EU. The ESS "Final Report" was published in late 1996 and aimed at identifying the main priorities of the R&D study that took place between 1997 and 2000 (the ESS R&D Council was created for this purpose in 1997). According to K. Clausen, ESS project director until 2001 and now one of the four ESS Directors, "*From 1997 to 2000, technical concepts in the project were refined, but no progress towards the realization of the ESS was made.*"[14]

In parallel, the OECD published in 1998 a joint report on neutron scattering facilities in the OECD countries and Russia[15] forecasting a significant decrease of the number of facilities until 2015. The OECD made several recommendations on the building of a new generation of neutron scattering facilities (Megascience Forum, 1998), recommendations applied by the US and Japan with their on-going neutron scattering projects.

In May 2000, the ESS Council decided to update the 1996 ESS project, adding four additional parameters (which led to the "Memorandum of Extension"):

- Study the technical and scientific interest of one short and one long pulse target station, instead of twoshort pulse target stations
- Consider superconducting accelerator technology
- Update the science case (especially in biology, biotechnology and earth sciences), regarding latest developments
- Study the multipurpose facility (MPF) option, called "CONCERT" (COmbined Neutron Centre for European Research and Technology).

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[10] Data from the International Energy Agency, www.iea.org.

[11] Data from the International Energy Agency, www.iea.org.

[12] Available on ESS web site.

[13] In this case, all results have then to be multiplied by 1.5.

[14] "*Status of the European Spallation Source (ESS) project* ", K.N. Clausen, Table Ronde ESS-Evalution stratégique, Société française de neutronique, 15-17 January 2001.

[15] "*A twenty years forward look at neutron scattering facilities in the OECD countries and Russia*", T. Springer, D. Richter, ESF and OECD, 1998.

The French CEA (Commissariat à l'énergie atomique) was in charge of the last point, through the CONCERT project, whose purpose was to integrate into one facility several projects in order to save costs. These main projects are:

- nuclear physics with radioactive beams
- material irradiation
- neutrino production
- **transmutation of nuclear wastes, through the development of a demonstrator.**

The ESS Council decided to determine the overall technical strategy (targets, instruments, accelerator) for the ESS project in June 2001, especially:

- the target stations
- the nature of the accelerator (superconducting or normal conducting)
- stand-alone or multipurpose facility (CONCERT option), based on an intermediate feasibility study from the CONCERT group.

At the June 2001 meeting, ESS Council finally decided not to follow the CONCERT proposals: « *The CONCERT team concluded that a single accelerator can serve more communities and is technically feasible, without the increase in power leading to substantial extra costs for the accelerator. But priority discussions and strategies of the various other communities - in particular those interested in transmutation of nuclear waste - have led first the CONCERT Supervisory Group, and now also the ESS Council, to decide that the priority must now go to a stand-alone ESS. This will be the overarching application of high intensity, high power proton accelerator-based facilities.* »[16]

The ESS Council decided to scale down the multi-purpose option,

- in order to limit the costs of the ESS project ("*The Council felt that ESS should not cost more than 1.5B€*"[17]), even if CONCERT extra costs are said to be "*reasonable*"[18], and not because of any technical problem as it has been sometimes specified[19].
- because of strategic choices of the communities especially interested in transmutation. In a note for the ESS Council, at the beginning of June 2001, Peter Tindemans, ESS chairman, recalled the conclusions on CONCERT, stating that "*The leading persons in transmutation have decided to explore collaboration with the USA and Japan, and then to abandon a European multipurpose project*".

This situation seems to have introduced a significant change in the ESS strategy after this meeting, the transmutation option officially being dropped by the ESS Council. However, in reality, the transmutation option remains open. (see below)

Who are these "*leading persons*", and why did they choose to leave ESS project? Little information is available today: Jean-Louis Laclare, from the CEA, who was CONCERT project director and one of the four ESS directors, decided to stop his direct participation in the ESS project, reflecting CEA's actual position on the project. As a ESS newsletter of November 2002 explained, "*The reason for Jean-Louis Laclare to step down is that budgetary problems and the decision to build Spirale-2 at GANIL have forced CEA to reduce its role to being an observer to the Council. The Council very much regrets that decision, but feels strongly encouraged by the support the French scientists and instrument team members keep giving to the ESS.*"[20]

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[16] ESS Newletter, July 2001.

[17] ESS Newsletter, May 2001.

[18] ESS/P2/01, A note for the ESS COUNCIL on CONCERT., Peter Tindemans, ESS Chairman, 3 June 2001.

[19] See the Swedish magazine "Todays Research" of 9-10 September 2002.

[20] ESS Letter, November 2002, available on Internet : http://www.ess-europe.de/documentation/LAST_NEWS_nov02.htm.

There is no doubt that without any French support, ESS reduces its chances to become reality. But what is the current strategy of France on this subject? Is it credible that *"budgetary problems*" have limited the French participation in ESS ? It seems more likely that French interests in a transmutation demonstrator in the framework of the ESS project have not been followed (for the moment?) and negotiations with other countries focussing on transmutation research have been intensified recently. During the OECD Forum Global Science 2001, the CEA announced its intention to develop a transmutation demonstrator, probably in the U.S., in collaboration with the U.S., Japan and other countries, essentially European ones. Other collaborations have also been investigated, for example between the CEA and the TransUranics Institute of Karlsruhe (Germany)[21].

Considering ESS' future in the area of transmutation, a key point to keep in mind is that the ESS facility, as well as all its competitors, are open projects, likely to be developed in several ways. It is **not a major issue to modify the accelerator**, for example in adapting a constant beam of protons **to carry out transmutation experiments** (injector replacement), as it **has been done for SINQ** (Paul Scherrer Institut, Switzerland). Even in choosing to build a stand-alone facility, as ESS did in June 2001, it is also not a major issue to add instruments to conduct further experiments, especially on transmutation. As K. Clausen said, speaking about non neutron scattering applications and, among them, irradiation, "*According to ESS terms of reference,* ***opportunities of these application should be maintained, without including this set of applications in the optimization criteria of the basic source parameters or the costing.***"[22] Moreover, the ESS Council specified in June 2001 that, if a multipurpose facility is abandoned, « *however, the design* [of the ESS project] *would include development potential.* »[23], which clearly means that **modifications of the ESS design could be made later to lead to the elaboration of a transmutation demonstrator**. This aspect is mentioned in the technical study of May 2002: " *The ESS design is rather flexible. It allows using the facility for other purposes. A number of these* ***would not require major new facilities and can be added later*** *if the site layout allows for the physical space.* " (See Annex 2).

After the meeting in June 2001, main ESS activities included:

- intensive lobbying actions, especially toward EU policymakers (for example letters to the ministers for research in Europe, Commissioner Busquin and the members of the European Strategy Forum on Research Infrastructures, ESFRI, consisting of civil servants from the EU member States consulted on new investments in research infrastructures)
- re-writing of the ESS 1996 studies considering the latest technical choices. These studies were presented on 16-17 May, 2002, during the "European ESS Meeting" in Bonn.

A few weeks after the May 2002 meeting, on 15 July 2002, the German Science Council (GSC, Wissenschaftsrat) released an assessment of nine large facilities projects, and among them ESS. This assessment led to a controversy because, in spite of its global positive point of view on the project, the report specified that « *the scientific case has to be advanced intensively and should be better intertwined with the rapid development of other characterisation tools.* »[24], a position rejected by the ESS Council, which decided to re-submit its project to the German Science Council.

For the future, the current ESS planning is as follows:

2004	Decision Phase (Project Approval and site design);
2005-2010	Construction Phase (Facility built);

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[21] "*European collaboration on nuclear wastes*", CEA, October 2002; available on CEA's web site : www.cea.fr

[22] "*Status of the European Spallation Source (ESS) project*", K.N. Clausen, Table Ronde ESS-Evalution stratégique, Société française de neutronique, 15-17 January 2001.

[23] European Spallation Source, 8th Meeting of the ESS R&D Council held in Abingdon, on 15 June 2001, Minutes.

[24] Wissenschaftsrat in its ESS assessment, 12 July 2002, http://www.wissenschaftsrat.de/texte/5373-02.pdf.

2011-2012	Commissioning Phase (Facility ready for users);
2013	Exploitation Phase.

I.C. Purposes of the ESS

I.C.1 Research Definition and Use

The previous section summarizes the ESS project evolution; ESS research areas are linked to this evolution. The first scientific case defined in the May 1996 study was modified between 1996 and 2000. The initial CONCERT collaboration (2000/2001) was aimed at adding four areas of research into the ESS project, especially linked to transmutation issues. The ESS study of May 2002 led to an updated version of the scientific case, which is summarized in Annex 3, based on the official presentation of the ESS Council. According to ESS estimates, the research areas covered by ESS would be likely to be used by a community of 4,000 to 5,000 scientists. However, we are not aware of any independent assessment of these figures.

I.C.2 Transmutation Applications

In the official ESS presentation of May 2002, no explicit reference to transmutation of nuclear wastes can be found. This is all the more surprising because the research on transmutation was explicitly mentioned in the first ESS study, through the Radioactive Nuclear Beam (RNB) instrumentation project: "***The ESS RNB facility could provide the nuclear data needed for nuclear waste transmutation.*** *In order to assess the usefulness of the many possible routes for transmuting long-lived and toxic fission products, we need a knowledge not only of the spallation reaction cross-sections of the isotopes of interest, but also of the spallation product distribution, to ensure we are not just replacing one problem with another.*" It is also surprising because transmutation experiments were the main purpose of the parallel CONCERT project, through material irradiation and the development of a demonstrator for the transmutation of nuclear wastes.

This strategic choice not to take into consideration transmutation research can be understood if we consider that ESS is a highly modular project. As mentioned above, ESS was designed to be flexible and it is not very difficult to imagine that this project is likely to be used for transmutation purposes if needed - i.e. if funded - by the interested communities. And at this crucial point for the ESS project, close to the decision phase, it very much looks like a tactical decision by the ESS Council to decrease the escalated cost projections and to exclude, from a first project definition, the highly controversial research on transmutation.

At the same time, it is important to note that part of the ESS Council decision in June 2001 was to develop two targets: a 50Hz short pulse and **a 16Hz long pulse**, rather than two short pulse targets. Even though it is still not easy to use pulsed beams for transmutation purposes, and if constant beams of protons remain the easiest way for nuclear wastes transmutation experiments, it is however possible to carry out transmutation experiments with pulsed proton beams if specific targets are used. As far as we know, **long pulse targets** are then required for transmutation (see annexes 4, 5 and 6). This means that, after minor adaptations, transmutation experiments could be carried out on the basis of the current ESS design. The German Research Council has noted "incorporation of irradiation facilities, e.g. for test irradiation of materials for nuclear fusion technology, in the long pulse target station" as one of "several conceivable ways in which the facility could enlarged or upgraded in the future." Also noted was that ESS "will advance accelerator technology which is a strategic core technology for e.g. nuclear waste transmutation, fundamental physics (ultra cold neutron and neutrino sources, radio-active ion beams), materials irradiation (e.g. for fusion facilities), medical accelerators and waste treatment." [25]

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[25] http://www.wissenschaftsrat.de/texte/5373-02.pdf, pages 16-17 and 40

II. Transmutation

II.A. The Context of Transmutation: No Waste Transmutation without Nuclear Reprocessing,

Transmutation research is primarily motivated by a basic consideration of radioactive waste management: the idea of transforming radioactive isotopes with a very long life into shorter lived isotopes.

Electricity production from nuclear energy produces several types of radioactive wastes, essentially:

- Fission products (from nuclear fission in the fuel)
- Activation products (neutron capture by atoms of the reactor itself)
- Transuranics (neutron capture by the nuclear fuel).

If we focus on wastes with a radioactive half-life of more than 10 years, we have to take into account transuranics and fission products. Transuranics, emitters of α-radiation, have the longest life and the highest radiotoxicity level. The main idea of transmutation is therefore:

- to reduce the global radiotoxic inventory of radioactive wastes and
- to reduce their half-life.

Three types of basic strategies have been proposed for the management of radioactive wastes:

- Long-term storage on surface
- Radwaste final surface disposal, subsurface or geological disposal
- Spent fuel reprocessing (separation of transuranics and fission products).

It should be noted that with the current reprocessing technologies, as applied at the UK Sellafield plant or the French La Hague facilities, the level of separation of long-lived isotopes is by far not sufficient in order to constitute the basis of a potential transmutation strategy. The current technologies do not even aim to efficiently separate out the various isotopes to be transmuted but are meant to extract plutonium and uranium for (potential) re-use. The current reprocessing strategy only displaces in time the need for final disposal of radioactive wastes This happens at high environmental and economic cost.[26]

If there were an efficient transuranics and fission product separation technology, two approaches could be considered for these extracted products:

- Transmutation: radioactive nuclides are transformed into stable nuclides through neutron captures. This approach could be carried out for fission products. However, the technology is still at the research and development level. It requires the efficient preliminary separation ofstable and radioactive nuclides (because stable nuclides are likely to become radioactive after neutron capture).
- Incineration: through a fission reaction, radioactive nuclides produce stable or short-lived nuclides, and release energy and a few neutrons. The approach could be applied for transuranics. Fast breeder or fast neutron reactors that have a negative breeding ratio – thus consuming more plutonium than they produce – operate in this mode.

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[26] For further information about the effects of reprocessing, see Mycle Schneider et al. « *Possible toxic effects from the nuclear reprocessing plants at Sellafield (UK) and Cap de La Hague (France)* », commissioned by the Scientific and Technological Option Assessment programme at the European Parliament, WISE-Paris, November 2001 (see http://www.wise-paris.org/english/stoa_en.html)

In fact, the term “transmutation” is often used to express the idea of “incineration”, as well as the idea of “transmutation”. The term “partitioning” is generally used for “separation”.

II.B. Several Theoretical Approaches, no Engineered Solution

Three main transmutation approaches have been studied:

- transmutation in thermal-neutron reactors;
- transmutation in fast-neutron reactors;
- accelerator-driven transmutation with sub-critical reactors.

In the framework of the reexamination of S&T (Separation and Transmutation) technology systems, the U.S. National Research Council was requested in 1991 by the U.S. Secretary of Energy to lead a global review of those technologies. A group of 29 mutlidisciplinary experts was created to study separation and transmutation, and the report on this vast, five year long research project was published in 1996[27]. The top level group has analyzed in depth all three approaches to transmutation, and in June 1997, the two icons of American nuclear engineering N.C. Rasmussen (chairman of the study group) and T.H. Pigford, presented the conclusions to the International Atomic Energy Agengy[28] (See also Annex 7). The Rasmussen Report underlines in particular that, considering the technical aspects of transmutation:

“*ALMR [advanced liquid-metal reactor[29]] and LWR [Light-water reactor[30]] transmutors would require several hundred years to reduce the total transuranic inventory by even a factor of 10 at constant electric power, and thousands of years for a hundred-fold reduction. For the same electrical power, the ATW [Accelerator-driven subcritical reactors for transmutation of waste] could reduce total transuranic inventory about tenfold more rapidly, because of its very high thermal-neutron flux. However, extremely low process losses would be required for the ATW.*”

In other words, according to the Rasmussen Report, using accelerator driven reactors and optimized processes, it would take hundreds of years to reduce a given transuranic inventory by a factor of hundred.

Moreover, as noted before, “*any of the transmutation fuel cycles considered here would require reprocessing and multiple recycling. Process losses would have to be reduced far below those in current reprocessing technology. Current technologies for fuel reprocessing, if constructed in the U.S., would be too expensive for transmutation fuel cycles. Costs and even the technical feasibility of new high-recovery reprocessing schemes proposed for transmutation are extremely uncertain.*”

Regarding research and development needs for transmutation, the conclusions of the Rasmussen Report are very clear, and shed a different light on transmutation project investment worldwide:

“*There is no immediate need for the U.S. to deploy any of these [three] proposed technologies for separations and transmutation, primarily because there is no present indication that S&T is necessary for the repository program to meet its goal. [...] The high cost of reprocessing and fabrication of recycle fuel is unfavorable in the current era of low-cost uranium and enrichment. Therefore, research and development on S&T cannot be viewed as urgent.*”

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[27] “*Nuclear Wastes - Technologies for Separations and transmutation*”, National Research Council, 1996.

[28] References mentioned below are taken from: “*Transmutation of radioactive waste : effect on the nuclear fuel cycle*”, N.C. Rasmussen, T.H. Pigford, International symposium on nuclear fuel cycle and reactor strategies : adjusting to new realities, IAEA, Austria, 3-6 June 1997.

[29] Fast-neutron reactor.

[30] Thermal-neutron reactor.

II.C. Spallation Sources: Existing Facilities and Planned Sources

There are around 26 neutron scattering facilities around the world, of which four are in Asia and Australia, 16 in Europe and Russia, and six in North America. Moreover, two major projects are under construction in Japan and US. Of these 26 facilities, 7 have designs quite similar to the ESS (especially considering spallation), although they are older and most of them have been equipped with subcritical reactors allowing transmutation studies:

- KENS Neutron Scattering Facility, KEK, Tsukuba, Japan (500 MeV)
- Kyoto University Research Reactor Institute (KURRI), Kyoto, Japan (46 MeV)
- Interfacultair Reactor Instituut, Delft University of Technology, Netherlands(3 MeV)
- ISIS Pulsed Neutron Facility, Rutherford-Appleton Laboratory, Oxfordshire, UK (800 MeV)
- Swiss Spallation Neutron Source (SINQ), Paul Sherrer Institut, Villigen, Switzerland (590 MeV)
- Intense Pulsed Neutron Source (IPNS), Argonne National Laboratory, Illinois, USA (450 MeV)
- Los Alamos Neutron Scattering Center (LANSCE), New Mexico, USA (800 MeV)

The existing continuous and pulsed neutron sources are listed respectively in Annexes 8 and 9. The characteristics of new generation spallation sources are outlined in Annex 10.

II.D. Transmutation Research in the EU Framework

The decision on ESS funding will have to be made by the EU before 2004. The present time represents a key period to submit such proposal at the European level, because the EU is officially creating (or planning to create) a European Research Area[31]. The negotiations around a European Framework Program[32] began at the end of 2000. From the beginning, ESS has clearly shown that one of its purposes is to develop the project on a European level, it is therefore obvious that ESS is attempting to become an integrated component of EU research policy.

The in-depth analysis of the EU "transmutation policy" is beyond the scope of this Memo. However, a short overview will allow the extraction of a certain number of aspects, for example considering the EU-funded projects in separation and transmutation. Some reference figures on the Fifth European Framework Program for research and technological development (FP-5) are given in footnote[33].

Would the ESS project be attractive for EU funding in the framework of transmutation research? The Sixth Framework Program (2002-2006), as well as previous Framework Programs, would have to be

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[31] "*Towards a European Research Area, Communication from the Commission*", COM (2000) 6, 18 January 2000, http://europa.eu.int/comm/research/area.html

[32] "*Making a Reality of the European Research Area: Guidelines for EU Research Activities (2002-2006)*", Communication from the Commission, COM (2000) 612, 4 October 2000, http://europa.eu.int/comm/research/area.html.

[33] See in particular :
- "*PARTITIONING AND TRANSMUTATION IN THE EURATOM FIFTH FRAMEWORK PROGRAMME*", Michel Hugon, Ved P. Bhatnagar, European Commission, in ACTINIDE AND FISSION PRODUCT PARTITIONING AND TRANSMUTATION, 6th Information Exchange Meeting, OECD/AEN-EU, Spain,, 11-13 December 2000.
- "*A European Roadmap for Developing Accelerator Driven Systems (ADS) for Nuclear Waste Incineration*", The European Technical Working Group on ADS, April 2001, p.63-104.
- for a broader assessment (nuclear energy) : "*Five year assessment report related to the specific program : nuclear energy*", A. Airaghi , L. Patarin (dir.), June 2000.

evaluated to find some answer to this question[34]. Global information on EU financial support for transmutation is given in footnote[35]. The orders of magnitude have to be compared with ESS financial requirements, especially considering that 80 to 85 % of ESS construction costs and 95 to 98 % of ESS operational costs are not funded by the host country and so still have to be identified.

Until March 2001, the total manpower commitment in the different member states of the EU involved in transmutation applications was approximately 300-400 my/y (man-years per year)[36], essentially on basic support for research and development.

The credits devoted to transmutation in the Sixth Framework Program represent about 30% of the "nuclear fission" budget line[37]. The total budget for the main separation and transmutation related projects taken into account in the Fifth Framework Program for 2000-2003 (see Annex 12) is 50 million euros, EU funding representing 50% of this amount.

Approximately 30 million euros have been devoted to basic transmutation research and development in 2001-2002 under the Fifth Framework Program. During the four year period of the Sixth Framework Program, a total of 90 million euros is devoted for waste management, not only including separation and transmutation but also geological disposal. Specific budgets for separation and transmutation will have to be compared to previous financial efforts by the EU (about 15 millions euros/year).

Accelerator Driven System related projects selected for funding under the Fifth Framework Program are listed in Annex 11 The projects were divided into three groups : partitioning/chemical separation, transmutation/technological support and acquisition of basic data.

The European Technical Working Group on Accelerator Driven Systems also led an interesting study on the cost and the possible distribution of EU funding under successive research Framework Programs of an Accelerator-driven system dedicated to transmutation (see Annex 13).
The similarities are remarkable between ESS and this EU "100 MW Accelerator Driven System". However, considering the relatively low EU budgets for separation and transmutation under the Framework Programs, it seems highly unrealistic to expect a major contribution to ESS given the current cost estimates.

However, during the debate on a potential European approach to nuclear safety and security of supply in November 2002, "*The Commission [...] found that the funding allocated to research on waste management is insufficient, despite the efforts made by the Joint Research Centre*[38]*. Consequently, this proposal sets out to support and step up the research efforts and to coordinate the national research programmes more closely. In due course, with the agreement of the industry and the Member States, the Commission intends to propose the creation of a Joint Undertaking, as provided for by Article 5 of*

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[34] The overall budget of FP-6 is 17 500 million euros (16 270 million euros for the EC program, 1 230 million euros for the Euratom program). Five specific Programs have been created: Integrating and strengthening the European Research Area (EC), Structuring the European Research Area (EC), Joint Research Centre activities (EC), Nuclear energy (Euratom) and Joint Research Centre activities (Euratom).

[35] Except for ESS-related information, most of the information given in this section is based on the report : "*A European Roadmap for Developing Accelerator Driven Systems (ADS) for Nuclear Waste Incineration*", The European Technical Working Group on ADS, April 2001.

[36] For ESS, the total commitment for R&D, on three years (1997-2000) was initially estimated to 264 Sy (Scientist years ; a scientist is an Assistant Professor and above ; administrative staff are generally excluded) in 1996 ESS study, Volume III.

[37] Report n°8, French National Assessment Commission on Radioactive Wastes, 2002.

[38] JRC FP-6 budget for nuclear activities : 290 million euros. The JRC is likely to support researches on ADS on its "nuclear" credits, and potentially other research of ESS on its non-nuclear credits.

the Euratom Treaty, to manage and steer research funding for radioactive waste management from the Joint Research Centre, the Member States and industry."[39]

At the European level, the future of ESS - i.e. its funding - will probably directly depend on the assessment of the European Strategy Forum on Research Infrastructures (ESFRI), already mentioned. This working group, reporting to EU Commissioner Busquin, is expected to submit its evaluation at the beginning of 2003.

Conclusion

The present preliminary analysis of the history and purpose of the ESS Project shows that nuclear waste transmutation experimentation has clearly been a strategic and logical orientation of the project throughout its development. The recent redefinition of the project in 2001 no longer mentions transmutation. However, the future adaptation of the redefined project in order to carry out transmutation experiments is both: feasible without major technically challenge and economically achievable (compared to overall costs).

While the present preliminary analysis does not allow for a final judgement, the 2001 reorientation of the project leaves the impression of a tactical move on behalf of the ESS Council in order to evacuate a highly controversial subject (nuclear waste transmutation) and increase public acceptability without compromising future options. The reasons presently preventing the ESS Council from maintaining the transmutation option are not technical, but rather seem to be political and financial in nature.

The ESS project further raises a number of fundamental questions, including:

• The viability of the project as a whole. What would be the result of a comprehensive social cost/benefit analysis of yet another accelerator based system, considering:

- the horrendous projected investment cost of some 1.5 billion euros and the projected annual expenditure of over 140 million euros;
- the significant electricity needs (at least 100 MW generating capacity, corresponding to the electricity consumption of more than 1.5 times the one of a city like Roskilde, representing over 30 % of the annual operational costs or some 9,000 euros per hour of operation);
- the significant underlying driving force motivated by some competition with the US and Japan beyond identifiable scientific rationale;
- the entirely unknown environmental and social impact of the project.

• The open door for the transmutation option. Transmutation is a highly questionable nuclear research orientation. A five year study of top level experts in the US consider that it would take hundreds of years to reduce a given inventory of long lived wastes by a significant factor using accelerator driven reactors and optimized processes. In fact, it seems that today the transmutation area allows to "recycle" a large number of otherwise jobless nuclear researchers. In the US, nuclear weapons research centers like Oak Ridge National Laboratories launched transmutation programs that occupy a significant number of scientists. In France, the issue is welcome as employment for a part of the huge number of scientists that have become redundant after the fast breeder reactor line was abandoned.

• No transmutation without nuclear reprocessing. It should not be forgotten that there can be no transmutation of long lived radioisotopes before they have been separated from irradiated nuclear fuels. The process is commonly called reprocessing. Current generation reprocessing plants are located at Sellafield in the UK and at La Hague in France. Together, these plants are the single largest sources

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[39] European Commission Representation in Ireland. Available on Internet : http://www.euireland.ie/news/trans/1102/nuclearsafetyapproach.htm.

of anthropogenic (manmade) radioactivity and lead to more than 80% of the radiation exposure of the European population from the nuclear industry. Transmutation would necessitate the highly uncertain development of much more efficient separation technologies for long-lived radioisotopes.

Annex 1

ESS Main Partners

European main partners[40]:

- European Science Foundation (ESF)
- European Neutron Scattering Association (ENSA)
- Austria (Neutron and Synchrotron sources Committee, NSC, Atominstitut der TU-Wien)
- Denmark (Risø National Laboratory-RNL)
- France (Commissariat à l'Énergie Atomique-CEA, Centre National de la Recherche Scientifique-CNRS/has become an observer with the intention to sign the new MoU as a full member, Institut Laue-Langevin-ILL)
- Germany (Forschungs-zentrum-FZ Jülich, Hahn-Meitner-Institut-HMI, Institut für Angewandte Physik)
- Italy (National Research Council-CNR, National Institute for the Physics of Matter-INFM)
- Netherlands (Interfaculty Reactor Institute-IRI)
- Spain (Research Centre for Energy, Environment and Technology-CIEMAT)
- Sweden (University of Uppsala)
- Switzerland (Paul Sherrer Institut-PSI)
- United Kingdom (Council for the Central Laboratory of the Research Councils-CCLRC i.e. Rutherford Appleton Laboratory and Daresbury Laboratory, EPSRC)

Worldwide partners:

- Russia (Joint Institute of Nuclear Research-JINR also representing the Institute of High Energy Physics, Institute for Nuclear Research of the Russian Academy of Sciences-INR, Frank Laboratory of Neutron Physics-Dubna)
- United States (Oak Ridge National Laboratory with the Spallation Neutron Source project)
- Japan (High Energy Accelerator Research Organization-KEK and Japan Atomic Energy Research Institute-JAERI joint project of high intensity proton accelerator)

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[40] As indicated by the ESS board (see http://www.ess-europe.de/ess_js/index.html) and in the German Science Council report (see http://www.wissenschaftsrat.de/texte/5373-02.pdf)

Annex 2

ESS as a Modular Research Instrument

ESS May 2002 Study, Volume III (Technical study)

I.2.7 Potential other usages

The ESS design is rather flexible. It allows using the facility for other purposes. A number of these would not require major new facilities and can be added later if the site layout allows for the physical space. For some applications major financial resources are necessary, the relevant communities should secure these.

The other usages being considered by the respective communities are:
1. An irradiation facility in one of the existing LP or SP target station.
2. A radioactive beam facility.
3. Production of radioisotopes.
4. An Ultra Cold Neutron source.
5. A Muon facility in the transfer line between rings and SP target.
6. A Neutrino facility in a cave below the SP target.

Provision for these other uses are not included in the project proposal and costs.

Annex 3

The Advantages of the ESS Project according to the ESS Official Presentation

Based on the May 2002 factsheets and reports

Scientific opportunities at ESS
Biology and Biotechnology
Polymers and Soft Matter
Earth and Environmental Science
Computer Simulation and Neutron Scattering
Engineering and Material Science
Amorphous and Disordered Materials
Chemistry and Chemical Structure
Solid State Physics
Particle Physics
Liquids

Major achievements of neutron scattering
Magnetic Structures
Elementary Excitations and Phase Transitions
Polymer Conformation and Dynamics
Structure and Dynamics of Liquids
Proton Positions and Motions in Biomolecules
Crystal Structures and Magnetism of High Temperature Superconductors
Concepts of Statistical Physics
Strain in Engineering Materials
Electro-weak Interaction
Quantisation of Neutron Waves in the Field of Gravity

ESS contributions to European research missions
Magnetoelectronics
Magnetic Neural Networks
Holographic Laser Discs
Drug Discovery
Enzymes in Food Productions
Unveiling Ancient Technologies
Hydrogen Energy Economy
Methane Clathrates: Energy Resource and Marine Hazard
Templating of Nanostructures
Nanomaterials for Transport and Traffic

Instumentation opportunities at ESS
Backscattering Spectrometers
Diffraction for Physical and Chemical Crystallograhy
Chopper Spectrometers
Diffraction for the Life Sciences
Quantum Leap in Performance
New Quality Multi-spectral Beams
More Efficient Beam Delivery
New Techniques for Unprecedented Resolutions/Enhanced Instrument Design Concepts

Annex 4

“Linac architecture for high power proton sources”

Jean-Michel Lagniel, CEA-Saclay, DSM-DAPNIA-SEA, France
XX International LINAC Conference, Monterey, California, August 2000.

“- Hybrid reactors and transmutation of nuclear waste
Hybrid reactors are based on an accelerator driven source of neutrons used to control the core of a subcritical nuclear reactor with a large degree of liberty in the choice of the fissile core. This constitutes a specific advantage in the transmutation of minor actinides and certain long-lived fission products. The actual design of hybrid systems leads to the use of a new generation of high-power proton accelerators with very high standards of reliability. The demonstrator stage should include a ~1 GeV proton accelerator with an initial power of 5 MW extendable to 20 MW. Operation at 50 Hz with pulses of constant peak intensity and variable length could be advantageous for power adjustment and setting and reactor diagnosis (measurement of k_{eff}). It remains to be determined whether under certain conditions pulsed operation is not liable to encourage power fluctuations in the sub-critical core.”

Annex 5

“Application of spallation neutron sources”

W.E. Fischer, Paul Scherrer Institut, Villigen, Switzerland

Proceedings of EPAC 2002, Paris, France, June 2002

“In the nineties accelerator driven energy systems were reconsidered again, but now with emphasis of transmutation of actinides in the context of waste management from used nuclear fuels. While the pulse structure is a basic mean to economize the neutronics of a neutron source, it is quite obvious that for such highest power “energy” – applications a d.c. beam is preferable. In view of this development a continuous spallation neutron source has been built and attached to the PSI cyclotron system, which delivers a 600 MeV continuous proton beam with a power beyond 1 MW. [...Considering spallation], for a pulsed source a synchrotron or a LINAC followed by a synchrotron type of storage ring can give the suitable time structure, that is pulses with a width of less than 1 μs and a repetition rate of typically 20 – 50 Hz. ”

Annex 6

“High power targets for spallation sources”

Tim Broome, Rutherford Appleton Laboratory, Chilton, Didcot, Oxon., UK
EPAC 1996, Barcelona, Spain, June 1996

“6 CONTINUOUS AND PULSED SOURCES
6.1 Fast pulse sources
A particular problem exists for targets on pulsed sources. When the duration of the pulse is short the heat is deposited faster than it can be conducted away. The resulting fast temperature rise in a solid target produces high transient thermal stress waves (sometime known as thermal shock). Typically, this will be an important consideration for pulse lengths less than a few microseconds. This effect is also a problem in liquid metal targets where the liquid transmits pressure waves to the target container resulting in high stresses. This is a major concern for the ESS mercury target [...]. Transient thermal stresses may well be the ultimate limit for the power of fast pulsed sources. A fast pulsed spallation source to provide thermal neutron beams for condensed matter research uses small, typically 0.5 - 1 litre hydrogenous moderators to slow down the fast neutrons from the target. They are sized to maintain short pulses (10 - 150 ms fwhm) and the designs incorporate neutron absorbers to eliminate neutrons moderated by coolant and the reflectors. In this case thermal neutron absorption in the target material is a positive advantage. These systems also require the target to be as compact as possible to maintain high neutron fluxes feeding the small moderators. Increasing the target size leads to a reduction on the neutron beam fluxes.

6.2 Continuous and quasi-continuous source.
For continuous and quasi-continuous spallation sources (pulse lengths ~200 ms or greater) the heat loading does not lead to the potentially high transient thermal stresses of the fast pulse targets. The total number of neutrons produced becomes a crucial quantity and minimum neutron absorption is then vital. This can be achieved by optimisation of the geometry and choice of target material. For these sources a more extended target generally has less of a penalty in neutron flux than in the case of fast pulsed sources. The consideration of neutron economy is very similar to that in reactor design.”

Conclusions of the U.S. Commitee on Separation Technologies and Transmutation Systems

(STATS)[41]

“ [...] our committee reached the following conclusions about the feasibility of reprocessing and transmutation and the impact on the U.S. repository program:

1. Separation and transmutation (S&T) of transuranics and certain long-lived fission products in spent nuclear reactor fuel is technically feasible and could, in principle, provide benefits to radioactive waste disposal in a geologic repository. However, **to begin to have a significant benefit for waste disposal, an entire S&T system consisting of many facilities would have to operate in a highly integrated manner for several decades to hundreds of years**[42]. The deployement of an S&T system that is extensive enough to have a significant effect on the disposition of the accumulated LWR [Light-water reactor] spent fuel would require **many tens to hundreds of billions of dollars and take several decades to implement.**

2. **The proposed R&D systems would require decades to centuries to achieve a significant net reduction in the total TRU [Transuranics] inventory relative to that of once-through LWR fuel cycle.**

3. The S&T systems differ widely in their state of technological maturity and present a broad spectrum of development issues, risks, costs, and schedules. The most mature system concept for transmuting transuranics and fission products, based on LWRs, needs fuel-cycle development and would require significant financial ressources and enormous institutional commitment to reach the point of deployment. The ALMR/IFR [Advanced liquid-metal reactor/Integral Fast Reactor] system for transmuting transuranics would require even more financial ressources and take longer to reach deployment. **The ATW** [Accelerator-driven subcritical reactors for transmutation of waste] **concepts would require major development before even the technical feasibility and chances ofsuccess can be realistically assessed.**

4. There is **no evidence that application of transmutation and its associates advanced reprocessing holds sufficient merit for the U.S to delay the development of its first nuclear waste repository** to contain commercialspent fuel. **Even if a transmutation system were in place, a geologic repository would still be needed.**

5. **Application of reprocessing and transmutation does not hold sufficient merit to abandon the once-through fuel cycle in the U.S.**

6. While the need for a second repository could be delayed by reprocessing and transmutation , there are several other ways, both legislative and technical, to increase the capacity of the first repository by a comparable amount.“

And concerning “research and development needs”:

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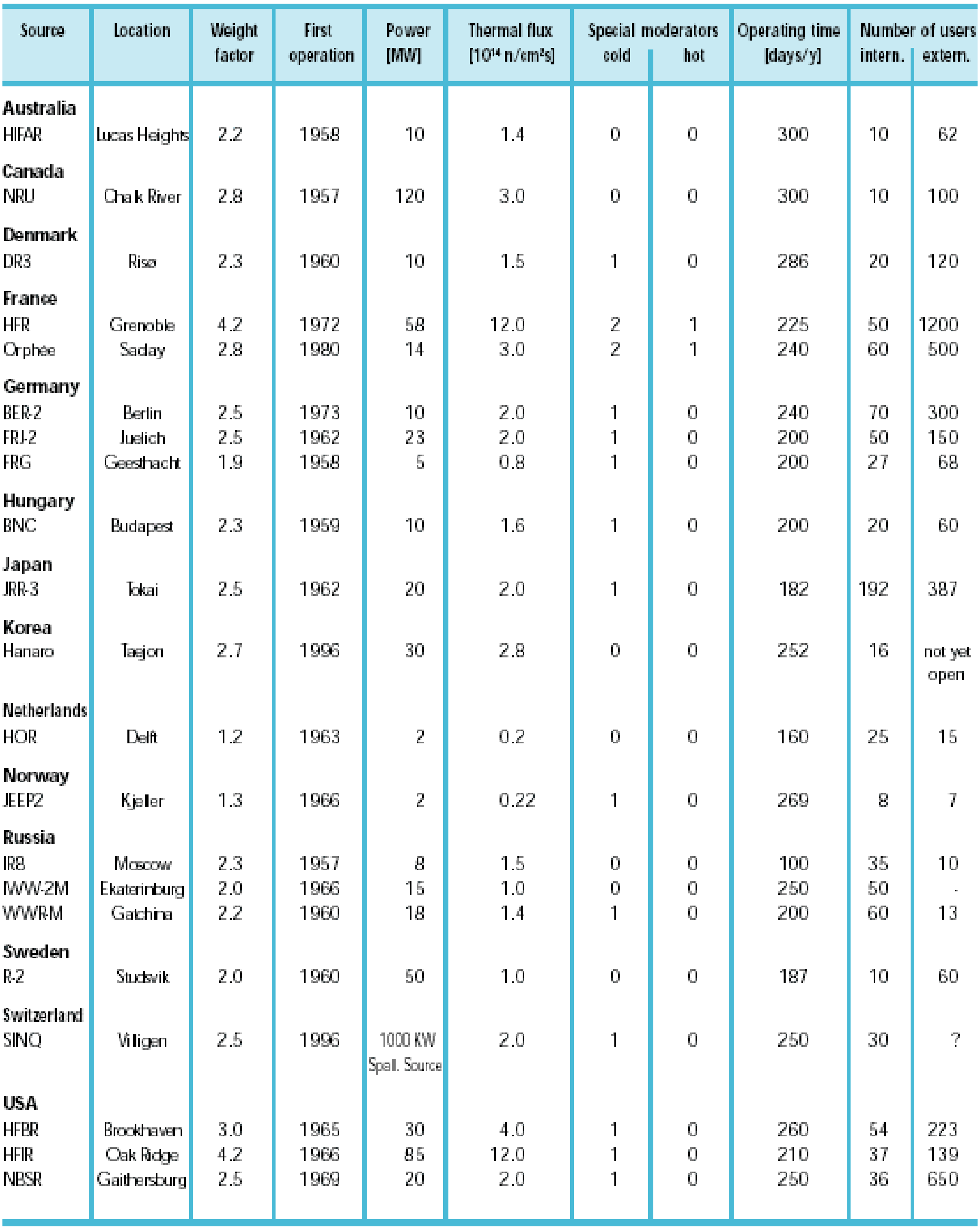
[41] N.C. Rasmussen (Chairman of the Commitee) and T.H. Pigford (member) in the article: « *Transmutation of radioactive waste : effect on the nuclear fuel cycle* », , International symposium on nuclear fuel cycle and reactor strategies : adjusting to new realities, IAEA, Austria, 3-6 June 1997.

[42] We underline, in the whole text.

“There is no immediate need for the U.S. to deploy any of these [three] proposed technologies for separations and transmutation, primarily because there is no present indication that S&T is necessary for the repositery programm to meet its goal. [...] The high cost of reprocessing and fabrication of recycle fuel is unfavorable in the current era of low-cost uranium and enrichment. Therefore, research and development on S&T cannot be viewed as urgent. For the near future of the U.S., S&T is best regarded as a contingency option. [...]”

Annex 8

Existing Continuous Neutron Sources

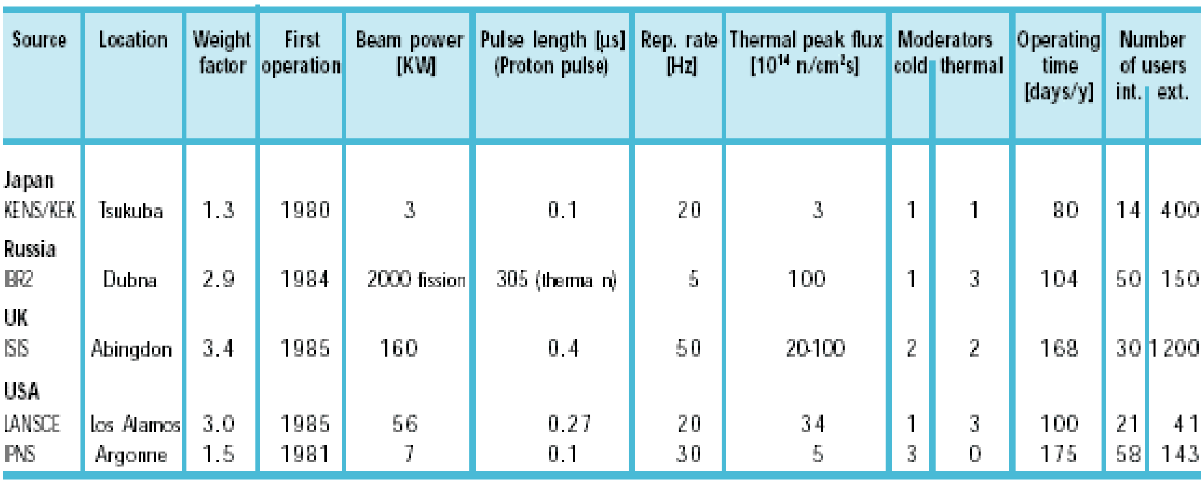


Source	Location	Weight factor	First operation	Power [MW]	Thermal flux [10^{14} n/cm²s]	Special moderators cold	hot	Operating time [days/y]	Number of users intern.	extern.
Australia										
HIFAR	Lucas Heights	2.2	1958	10	1.4	0	0	300	10	62
Canada										
NRU	Chalk River	2.8	1957	120	3.0	0	0	300	10	100
Denmark										
DR3	Risø	2.3	1960	10	1.5	1	0	286	20	120
France										
HFR	Grenoble	4.2	1972	58	12.0	2	1	225	50	1200
Orphée	Saclay	2.8	1980	14	3.0	2	1	240	60	500
Germany										
BER-2	Berlin	2.5	1973	10	2.0	1	0	240	70	300
FRJ-2	Juelich	2.5	1962	23	2.0	1	0	200	50	150
FRG	Geesthacht	1.9	1958	5	0.8	1	0	200	27	68
Hungary										
BNC	Budapest	2.3	1959	10	1.6	1	0	200	20	60
Japan										
JRR-3	Tokai	2.5	1962	20	2.0	1	0	182	192	387
Korea										
Hanaro	Taejon	2.7	1996	30	2.8	0	0	252	16	not yet open
Netherlands										
HOR	Delft	1.2	1963	2	0.2	0	0	160	25	15
Norway										
JEEP2	Kjeller	1.3	1966	2	0.22	1	0	269	8	7
Russia										
IR8	Moscow	2.3	1957	8	1.5	0	0	100	35	10
IVV-2M	Ekaterinburg	2.0	1966	15	1.0	0	0	250	50	-
WWR-M	Gatchina	2.2	1960	18	1.4	1	0	200	60	13
Sweden										
R-2	Studsvik	2.0	1960	50	1.0	0	0	187	10	60
Switzerland										
SINQ	Villigen	2.5	1996	1000 KW Spall. Source	2.0	1	0	250	30	?
USA										
HFBR	Brookhaven	3.0	1965	30	4.0	1	0	260	54	223
HFIR	Oak Ridge	4.2	1966	85	12.0	1	0	210	37	139
NBSR	Gaithersburg	2.5	1969	20	2.0	1	0	250	36	650

Source: "*A twenty years forward look at neutron scattering facilities in the OECD countries and Russia*", D. Richter and T. Springer for the OECD Megascience Forum with ESF, November 1998.

Annex 9

Existing Pulsed Neutron Sources

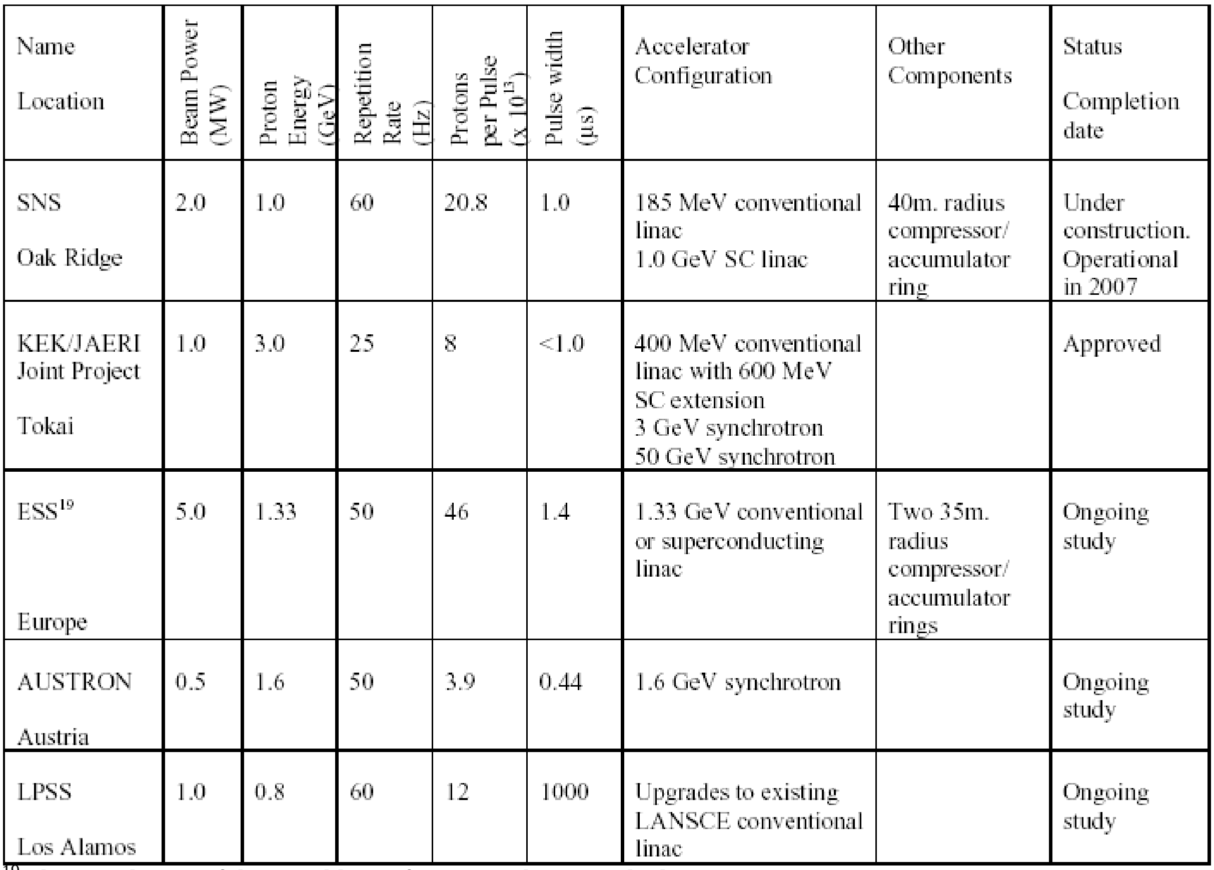


Source	Location	Weight factor	First operation	Beam power [KW]	Pulse length [µs] (Proton pulse)	Rep. rate [Hz]	Thermal peak flux [10^{14} n/cm^{2}s]	Moderators		Operating time [days/y]	Number of users	
								cold	thermal		int.	ext.
Japan												
KENS/KEK	Tsukuba	1.3	1980	3	0.1	20	3	1	1	80	14	400
Russia												
IBR2	Dubna	2.9	1984	2000 fission	305 (therma n)	5	100	1	3	104	50	150
UK												
ISIS	Abingdon	3.4	1985	160	0.4	50	20-100	2	2	168	30	1 200
USA												
LANSCE	los Alamos	3.0	1985	56	0.27	20	34	1	3	100	21	41
IPNS	Argonne	1.5	1981	7	0.1	30	5	3	0	175	58	143

Source: "*A twenty years forward look at neutron scattering facilities in the OECD countries and Russia*", D. Richter and T. Springer for the OECD Megascience Forum with ESF, November 1998.

Annex 10

Characteristics of the New Generation of Regional Spallation Neutron Sources



Name Location	Beam Power (MW)	Proton Energy (GeV)	Repetition Rate (Hz)	Protons per Pulse (x 10^{13})	Pulse width (µs)	Accelerator Configuration	Other Components	Status Completion date
SNS Oak Ridge	2.0	1.0	60	20.8	1.0	185 MeV conventional linac 1.0 GeV SC linac	40m. radius compressor/ accumulator ring	Under construction. Operational in 2007
KEK/JAERI Joint Project Tokai	1.0	3.0	25	8	<1.0	400 MeV conventional linac with 600 MeV SC extension 3 GeV synchrotron 50 GeV synchrotron		Approved
ESS[19] Europe	5.0	1.33	50	46	1.4	1.33 GeV conventional or superconducting linac	Two 35m. radius compressor/ accumulator rings	Ongoing study
AUSTRON Austria	0.5	1.6	50	3.9	0.44	1.6 GeV synchrotron		Ongoing study
LPSS Los Alamos	1.0	0.8	60	12	1000	Upgrades to existing LANSCE conventional linac		Ongoing study

[19] This is only one of the possible configurations being studied.

Source: “*High-Intensity Proton Beam Facilities*”, OECD Global Science Forum Workshop on Strategic Policy Issues, Paris, September 25/26, 2000.

Annex 11

Partitioning & Transmutation-Related Projects Funded under the 5th European Framework Program

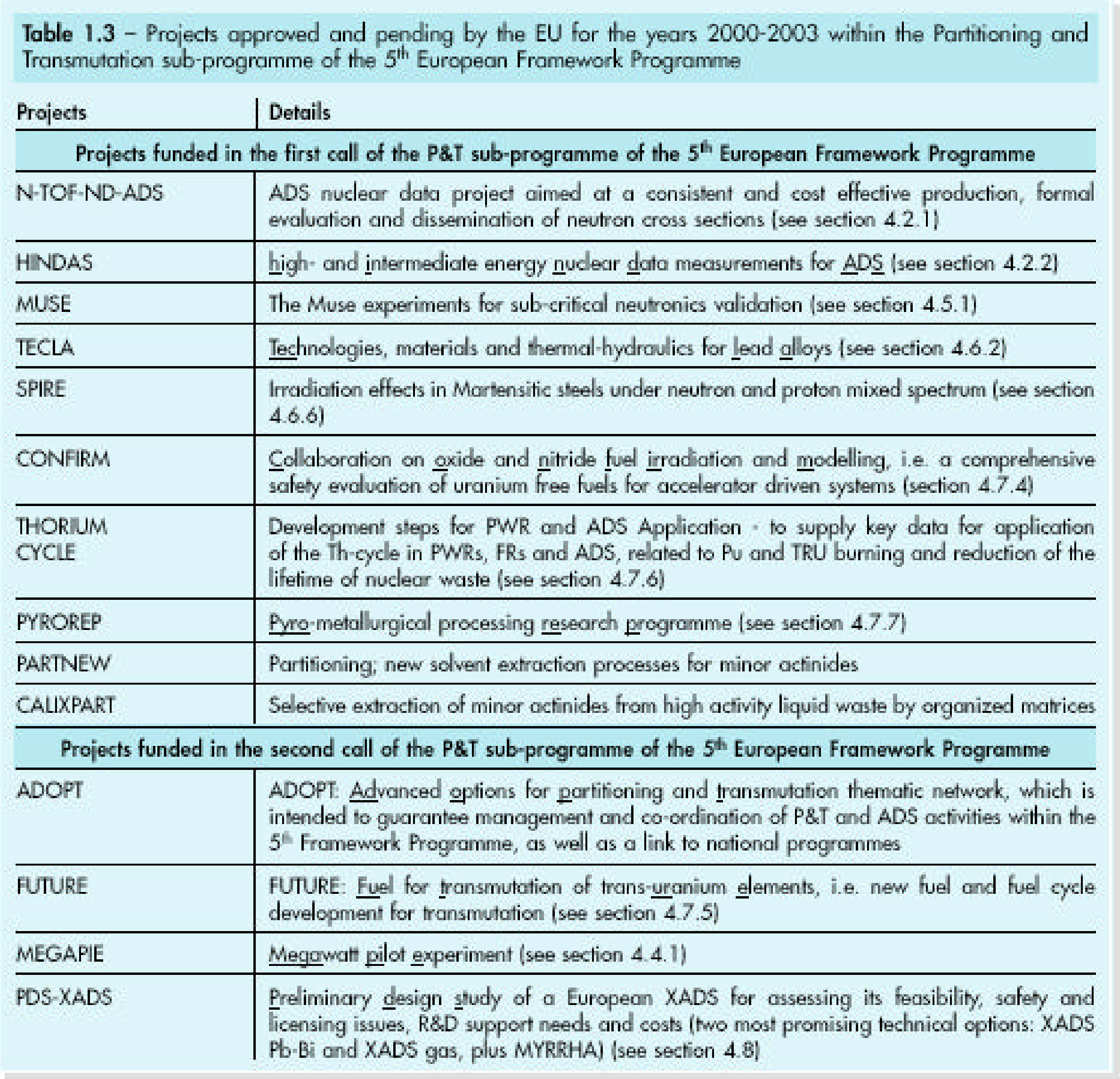


Table 1.3 – Projects approved and pending by the EU for the years 2000-2003 within the Partitioning and Transmutation sub-programme of the 5th European Framework Programme

Projects	Details
Projects funded in the first call of the P&T sub-programme of the 5th European Framework Programme	
N-TOF-ND-ADS	ADS nuclear data project aimed at a consistent and cost effective production, formal evaluation and dissemination of neutron cross sections (see section 4.2.1)
HINDAS	high- and intermediate energy nuclear data measurements for ADS (see section 4.2.2)
MUSE	The Muse experiments for sub-critical neutronics validation (see section 4.5.1)
TECLA	Technologies, materials and thermal-hydraulics for lead alloys (see section 4.6.2)
SPIRE	Irradiation effects in Martensitic steels under neutron and proton mixed spectrum (see section 4.6.6)
CONFIRM	Collaboration on oxide and nitride fuel irradiation and modelling, i.e. a comprehensive safety evaluation of uranium free fuels for accelerator driven systems (section 4.7.4)
THORIUM CYCLE	Development steps for PWR and ADS Application - to supply key data for application of the Th-cycle in PWRs, FRs and ADS, related to Pu and TRU burning and reduction of the lifetime of nuclear waste (see section 4.7.6)
PYROREP	Pyro-metallurgical processing research programme (see section 4.7.7)
PARTNEW	Partitioning; new solvent extraction processes for minor actinides
CALIXPART	Selective extraction of minor actinides from high activity liquid waste by organized matrices
Projects funded in the second call of the P&T sub-programme of the 5th European Framework Programme	
ADOPT	ADOPT: Advanced options for partitioning and transmutation thematic network, which is intended to guarantee management and co-ordination of P&T and ADS activities within the 5th Framework Programme, as well as a link to national programmes
FUTURE	FUTURE: Fuel for transmutation of trans-uranium elements, i.e. new fuel and fuel cycle development for transmutation (see section 4.7.5)
MEGAPIE	Megawatt pilot experiment (see section 4.4.1)
PDS-XADS	Preliminary design study of a European XADS for assessing its feasibility, safety and licensing issues, R&D support needs and costs (two most promising technical options: XADS Pb-Bi and XADS gas, plus MYRRHA) (see section 4.8)

Source : The European Technical Working Group on ADS.

Annex 12

Main facilities and projects of relevance to ADS in Europe

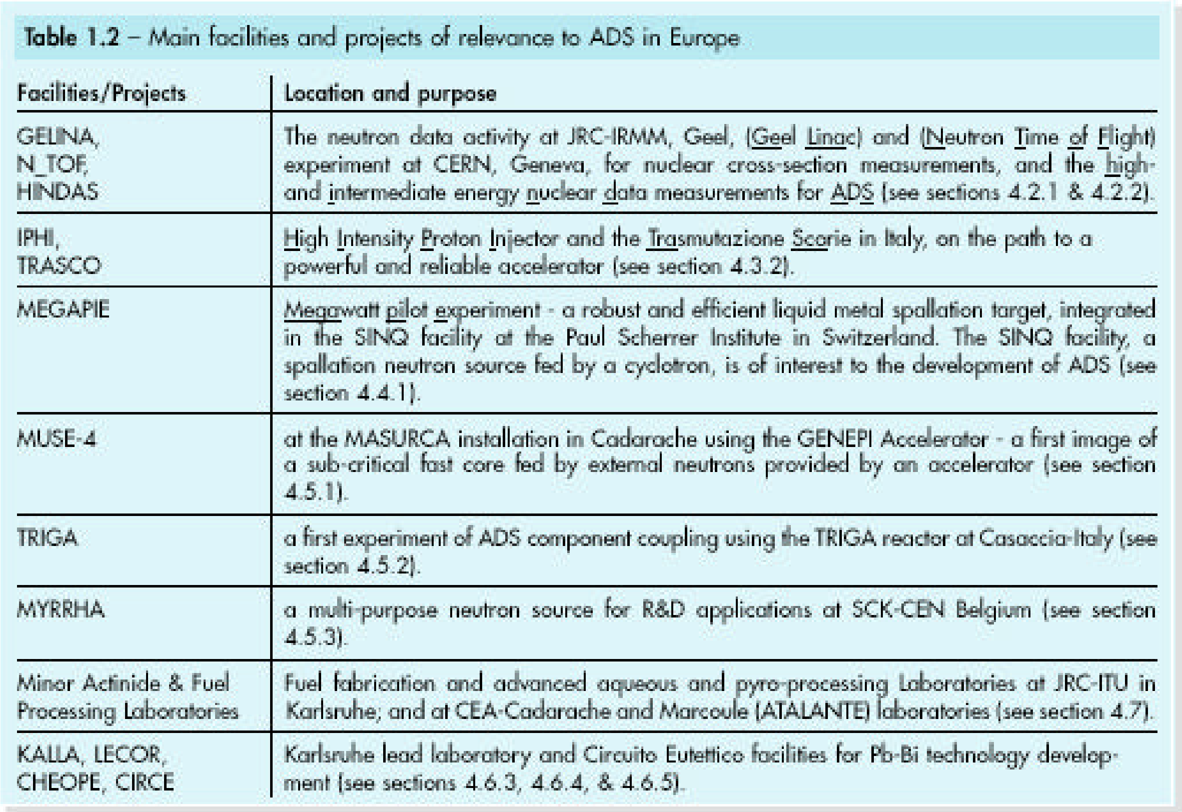


Table 1.2 – Main facilities and projects of relevance to ADS in Europe

Facilities/Projects	Location and purpose
GELINA, N_TOF, HINDAS	The neutron data activity at JRC-IRMM, Geel, (Geel Linac) and (Neutron Time of Flight) experiment at CERN, Geneva, for nuclear cross-section measurements, and the high- and intermediate energy nuclear data measurements for ADS (see sections 4.2.1 & 4.2.2).
IPHI, TRASCO	High Intensity Proton Injector and the Trasmutazione Scorie in Italy, on the path to a powerful and reliable accelerator (see section 4.3.2).
MEGAPIE	Megawatt pilot experiment - a robust and efficient liquid metal spallation target, integrated in the SINQ facility at the Paul Scherrer Institute in Switzerland. The SINQ facility, a spallation neutron source fed by a cyclotron, is of interest to the development of ADS (see section 4.4.1).
MUSE-4	at the MASURCA installation in Cadarache using the GENEPI Accelerator - a first image of a sub-critical fast core fed by external neutrons provided by an accelerator (see section 4.5.1).
TRIGA	a first experiment of ADS component coupling using the TRIGA reactor at Casaccia-Italy (see section 4.5.2).
MYRRHA	a multi-purpose neutron source for R&D applications at SCK-CEN Belgium (see section 4.5.3).
Minor Actinide & Fuel Processing Laboratories	Fuel fabrication and advanced aqueous and pyro-processing Laboratories at JRC-ITU in Karlsruhe; and at CEA-Cadarache and Marcoule (ATALANTE) laboratories (see section 4.7).
KALLA, LECOR, CHEOPE, CIRCE	Karlsruhe lead laboratory and Circuito Eutettico facilities for Pb-Bi technology development (see sections 4.6.3, 4.6.4, & 4.6.5).

Source : The European Technical Working Group on ADS

Annex 13

Estimated cost for the development of a 100 MW accelerator driven system

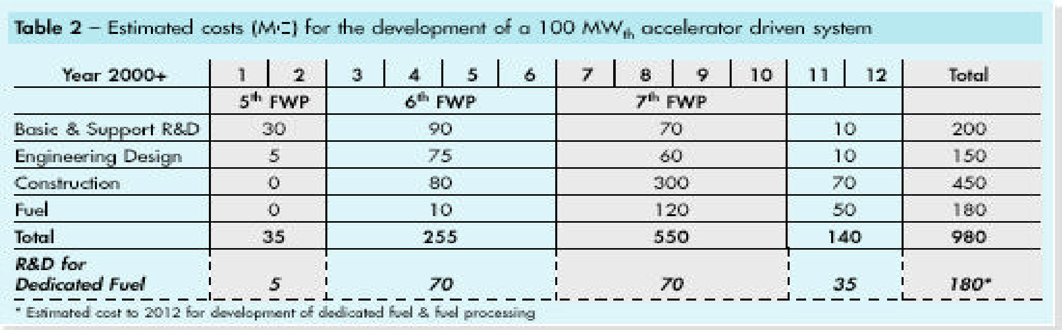


Table 2 – Estimated costs (M€) for the development of a 100 MW_{th} accelerator driven system

Year 2000+	1	2	3	4	5	6	7	8	9	10	11	12	Total
	5th FWP		6th FWP				7th FWP						
Basic & Support R&D	30		90				70				10		200
Engineering Design	5		75				60				10		150
Construction	0		80				300				70		450
Fuel	0		10				120				50		180
Total	**35**		**255**				**550**				**140**		**980**
R&D for Dedicated Fuel	*5*		*70*				*70*				*35*		*180**

* Estimated cost to 2012 for development of dedicated fuel & fuel processing

Source : The European Technical Working Group on ADS