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EXECUTIVE SUMMARY

The TRADE experiment, to be performed in the TRIGA reactor of the ENEA-Casaccia Centre, consists in the coupling of an external proton accelerator to a target to be installed in the central channel of the reactor scrammed to sub-criticality.

This pilot experiment, aimed at a global demonstration of the ADS concept, is based on an original idea of Carlo Rubbia, presented at CEA in October 2000.

A first feasibility report was produced on June 2001 by an ENEA (and partners) and CEA Working Group[1] and delivered to the ENEA/CEA management on July 2001.

This first report elucidated the representativity of the foreseen experiments in terms of dynamic behaviour, reactivity control, proton current/power relation, operation at start-up and shut-down, external source importance measurements, etc..

The type of target, its cooling and coupling to the reactor at power was also addressed.

The range of sub-criticality levels that can be explored was indicated to be between k = 0.90 (i.e. source dominated mode) and k = 0.99 (i.e. reactor feedback dominated mode).

Finally, an overall lay-out of the experiment was set up and the safety and licensing aspects were analysed at a very preliminary stage.

The present revision of the feasibility report adds a number of relevant features, according to a request by the CEA and ENEA management.

In particular:

- a proposal for a 115MeV-2mA super-conducting cyclotron for driving the TRADE experiment has been included, according to a Preliminary Conceptual Design proposed by the AIMA-Company and under evaluation by an International Panel of Independent Experts;
- the new lay-out of the facility takes into account a preliminary conceptual study of the beam transport line;
- the shielding and activation aspects have been treated in a preliminary way, in order to gain insight on the dose issues;
- the safety and licensing aspects related to the plant modifications induced by the TRADE experiment were further developed, adding new considerations on general safety criteria, possible accident initiators and a preliminary hazards analysis.

[1] The Working Group composition is given in Appendix 1

As far as this last point, a number of contacts have been recently established with the Italian Regulatory Body (ANPA), and a positive dialogue has been initiated which has lead at jointly defining the main phases of the envisaged licensing process.

Finally, a preliminary cost and time schedule evaluation has been worked out.

The results of these new studies confirm the general conclusions of the 2001 report as far as feasibility, and provide further credibility to a realistic implementation of the experiment in the time horizon of 2006-2008.

The major conclusions of the new studies indicate that:

General layout configuration

The modifications proposed for the existing TRIGA reactor and the new systems have been conceived and will be engineered taking into account the following guidelines:

- use of the free space outside the reactor building to the widest possible extent;
- minimum or no impact on the load-bearing structures of the reactor building;
- minimum modification to the reactor.

The overall layout of the accelerator-driven TRIGA facility shown in the present report, has been slightly modified with respect to the previous version (June 2001), in particular to fit into the layout a preliminary design of the beam transport line.

Accelerator

As far as the TRADE experiment, the accelerator task is to provide a maximum proton power of hundred kW; the present solution, based on a 115 MeV proton beam with a maximum intensity of 1-2 mA, is a cyclotron designed by the AIMA Company, that delivered a Preliminary Conceptual Design Report in November 2001.

The cyclotron accelerates up to 1 mA of $^2H^+$ ions internally, up to 230 MeV. A couple of 115 MeV protons for each $^2H^+$ ion is extracted by a carbon stripping foil and after an additional complete orbit in the magnet. A magnetic focusing channel directs the proton beam out of the machine. By means of an arrangement of electrostatic and magnetostatic elements placed inside the machine, the cyclotron can also extract a 230 MeV $^2H^+$ ion or even a deuteron beam. This beam can be used for other applications, eventually requiring a stripping process ($^2H^+$), or for radioisotope production.

Due to the novelty of the AIMA accelerator design, the above mentioned evaluation of the International Panel of Independent Experts, set up by ENEA, is a key point, in order to consolidate the overall project schedule.

Beam transport line

The Cyclotron to Target Beam Transport line (CTBT) task is to bring the beam from the cyclotron to the target, giving it a predetermined shape, typically a round beam 26 mm diameter at 2σ. The beam line can be schematically divided in three main parts. The first is a Matching Section (MS) by which the cyclotron beam is transported to a point in the cyclotron vault. The second is a Straight Transport

Line (STL) by which the beam is injected in the third section, the Final Bending (FB) by which the beam is directed to the target. The STL extends in the TRIGA building. It is surrounded by a concrete shielding that hangs from the cyclotron vault and protrudes in the TRIGA building.

In order to keep the shielding as light as possible, the STL is required to be a very low particle loss beam line (1 nA/m).

The FB is composed by a magnetic bending symmetric system with a few quadrupoles set in a way to form an image on the target of the beam in a point of the STL.

Safety and licensing aspects and constraints

Preliminary actions and documentation, to be submitted to "Ministero Attività Produttive" (MAP) and to the Italian Regulatory Body (ANPA), to obtain TRIGA reactor operation license extension for five more years, are almost completed.

Furthermore, the recent interactions with ANPA has clarified the main guide lines of the licensing process of the TRADE experiment, as well as the documentation to be prepared by the TRADE project, according to the Italian national legislation and to the ANPA Technical Guides.

Two independent licensing processes have to be implemented: a standard licensing procedure for the cyclotron and a separate one regarding the plant modification for hosting the TRADE experiment.

As far as the *plant modification licensing*, the process foresees two main stages.

Stage 1 is a very quick process to be started soon after the completion of the feasibility study. The request of authorisation must include a technical document prepared according to the ANPA's Technical Guide n. 2. Within a couple of months, MAP delivers a first authorisation on the general feasibility of the experiment, along with the procedure to be implemented in the second stage.

At the moment, it is envisaged that the second stage should develop according to ANPA's Technical Guide n. 4. If this will be the case, a reference design of the whole facility (so called "progetto d'insieme") and two detailed design (so called "progetti particolareggiati") for the beam transport line and the core design have to be prepared and submitted to ANPA, which will be the only national authority involved in the process.

In any case, the TRADE experiment has to be regarded as a sub-critical experiment to be performed in an existing critical reactor, and not as a new sub-critical facility.

The main design limitations to TRADE experiment have also been discussed with ANPA.

The preliminary safety analysis, related to the plant modifications induced by the TRADE experiment, has allowed to identify three scenarios in which the TRADE experiment could possibly introduce new initiators of accidents: uncontrolled withdrawal of regulating rod without scram, rapid loss of tank water and mechanical damage to the fuel. Nevertheless, the bounding hazards analysis of these new scenarios has demonstrated that the TRADE experiment does not present an unacceptable new hazard to the public or workers at the facility.

Finally, a preliminary shielding, activation and dose analysis, concerning the beam transport line and its interface with the TRIGA structures, has been carried out. The results indicate that, if the beam losses will be kept below 1 nA/m and an appropriate but feasible concrete shield is placed around the

beam transport line and, locally, over the bending magnet at the top of the reactor pool, the dose rates to exposed workers in the accessible areas and the individual dose to non exposed workers and to the population are below the maximum allowable limit imposed by the national legislation.

Milestones and Time Schedule

The present phase, started in February 2001, ends with the completion of the ***feasibility study*** (March 2002).

According to the discussion with ANPA, the Working Group is now preparing a technical documentation to be submitted – by the end of April - to the "Ministero delle Attività Produttive" (MAP) and to ANPA, in order to obtain a preliminary authorisation of feasibility of the plant modification by June 2002 (along with the definition of the second stage of the licensing process of the plant modification).

This authorisation and the signature of a Memorandum of Understanding (MOU) among the partners of the initiative (CEA, ENEA, and possible other institutions), are crucial elements for the decision to go ahead with project.

If this MOU will be signed by fall 2002, the following time schedule is envisaged:

- ***Preliminary design*** from fall 2002 up to mid-2003. In parallel, preliminary in-pile physics measurements could also be performed in the existing TRIGA reactor over the second half of 2002, before shutting down the plant to implement some necessary upgrades of TRIGA, which will then be ended around June 2003.
- ***Detailed engineering design*** between the second trimester of 2003 and fall 2004. In parallel to the detailed design, the licensing process of the cyclotron and of the plant modification (second stage) will take place, with a MAP authorization assumed to be around the end of 2003. In parallel, also a full program of physics in-pile sub-critical measurements using external neutron sources will be carried out from July 2003 up to June 2004, when the present TRIGA reactor will shut-down.
- ***Construction*** phase, including site preparation and TRIGA modifications, from beginning of 2004 to beginning of 2006.
- ***Installation*** phase, followed by the ***commissioning*** tests, over 2006.
- TRADE ***start-up experiments*** in the first half of 2007, after formal ANPA approval for operation.
- ***Full-power operation*** from mid-2007 up to 2009.

Cost estimate

A preliminary overnight vendor cost evaluation, subject to confirmation when a complete and consistent design will be available, leads to the following figures:

- Hardware: 33 M€ (of which 88% for the accelerator, the beam transport line and the beam test station);
- Manpower: 121 man.years, to be provided in-kind by partners and by engineering companies.

It has to be noted that further 4.3 M€ are necessary for TRIGA upgrading. Moreover, additional 3.6 M€ for optional fresh fuel procurement and 0.7 M€ for irradiated components disposal, final TRADE dismantling and TRIGA restoration have to be considered.

These costs do not include taxes, contingencies and owner's costs (TRADE operation).

Conclusions

The TRADE experiment is an essential demonstration of the ADS concept. The present investigations indicate that no show-stoppers have been found in the way to its realisation.

Of course, a project organisation should be put in place as soon as possible, together with an appropriate supervising Steering Committee.

As far as the crucial choice of the accelerator, the evaluation report of the International Panel of Independent Experts will enable to consolidate the present reference choice.

The project will benefit from an – as soon as possible - opening to selected external partners, sharing responsibilities, manpower and funding.

It is reminded that a green light to the project in fall 2002 is mandatory to keep the 2006 deadline for the start-up of the TRADE experiment.

As far as Europe, the TRADE experiment offers an unique opportunity for funding in the 6^{th} and 7^{th} Framework Program, as a major focus for transmutation projects, and it is suggested to start discussions on this subject at the appropriate level.

The Working Group, although its mission, as assigned by the ENEA and CEA management, is completed with the present report, will continue its activity in order to conclude some technical analysis (e.g. the natural convection cooling case for the target/core system, a bending magnet preliminary design, neutronic benchmarks, etc.), and to prepare the documentation to be submitted to MAP and ANPA, as indicated previously.