# STATUS OF THE INFN HIGH CURRENT SC PROTON LINAC FOR NUCLEAR WASTE TRANSMUTATION

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*Abstract*

INFN, jointly with ENEA, is working at the design study for an accelerator driven waste transmutation subcritical system, TRASCO. In particular, our group is studying the high energy section, above 100 MeV, of the high power (> 30 MW) proton linac driver at 352 MHz, following the guidelines we presented at the Linac'96 Conference. The funded activities include the overall conceptual design of the three section SC linac and the development and tests of prototypes for the cavities and cryomodules. An overview of the status and perspectives of these activities will be given in this paper.

## 1 THE TRASCO PROJECT

The TRASCO Project is a two year funded (10 M$) program in which INFN, jointly with ENEA and various Italian industries, will work on the design study of an accelerator driven waste transmutation subcritical system. TRASCO is an Italian acronym for Transmutation (TRAsmutazione) of Waste (SCOrie).

This program is in line with the growing European consensus, promoted by Carlo Rubbia through the idea of the Energy Amplifier, on a long term reconsideration of the civil use of nuclear power, based on a final solution of the waste accumulation problem. While similar programs are underway in the US and in Japan, in Europe the various national efforts are coordinating through the signature of Memoranda of Understanding, like the one recently signed by INFN, CEA and IN2P3 for a common effort in the accelerator technology development. Another MOU signed with the CERN group led by E. Chiaveri will give us the opportunity to make use of the wide experience gained so far in the production and commissioning of the LEP2 cavities. In particular, the cavity prototypes planned for TRASCO will be treated and tested at the CERN premises.

The aim of our specific effort in this preliminary, and short-termed, program is to set the feasibility of a high beam power proton linac based, whenever possible, on the "cheap" CERN technology developed for the LEP2 superconducting cavities. This is an extremely attractive option, since it allows the possibility to make use of large and expensive facilities, existing at CERN and at various European companies, for the studies on prototypes.

The low energy section of the machine, up to 6 MeV, is under study by others INFN groups (at LNL and LNS), in the framework of the collaboration with CEA and IN2P3. While a working prototype of the source is in operation at Saclay, the design and development of the CW, 6 MeV, RFQ, similar to the one developed for APT at LANL, is considered one of the major technological tasks.

The medium energy part, up to 100 MeV, is in study by INFN/LNL, and will take advantage of a contract signed with a qualified industry.

## 2 THE LINAC DESIGN

The reference linac design for the high energy section of the TRASCO linac has been set in Refs. [1] and [2]. The 100 to 1600 MeV linac is split three sections, with synchronous cavity $\beta$ of 0.5, 0.65 and 0.85. Transverse focusing is provided by a periodic doublet lattice, with cell length of 8, 11.2 and 15.3 m, respectively.

### *2.1 Beam dynamics simulations*

An intensive beam dynamics activity has started, in order to verify the performances of the linac design with multiparticle codes. An "ad hoc" simulation code has been developed for the beam dynamics in the elliptical shaped cavities, employing a fast 3D Poisson solver, based on multigrid algorithms, for the treatment of the nonlinear space charge fields. The results of this simulations are presented in a separate contribution to these Proceedings[3]. In Figure 1 we show the rms, 90% and 100% emittances along the linac for the nominal current of 25 mA, and a typical simulation of 100.000 particles. The cells at the transitions have been used for transverse and longitudinal matching across the three sections. The rms emittance growth is limited to below 10% and the total emittance increases by a factor < than 2.

The ratio between the beam aperture and the transverse rms beam size is well above 25 all along the linac. This, together with the small number of betatron wavelengths in the linac (few tens), gives us a great confidence that, with such a design, the halo formation in the SC linac would not be a serious problem.

The simulations were performed for a nominal current of 25 mA, the goal being that of a driver for a prototype transmutation plant. An increase of the linac current up to 100 mA has not been studied yet in full details.

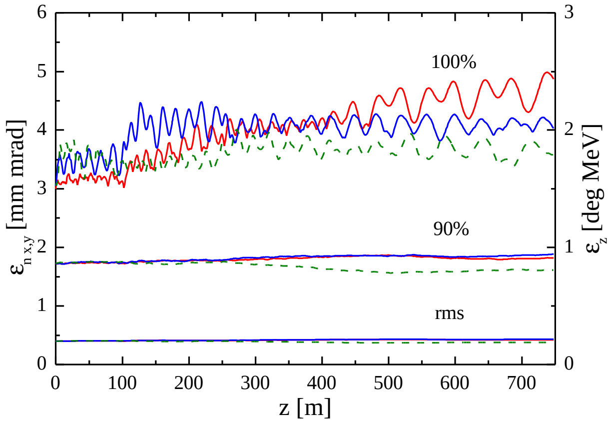


Figure 1: The rms, 90% and total (100%) emittances along the linac The solid curves are the transverse emittances, (left axis) and the dashed curve is the longitudinal emittance (right axis). The simulation has been performed with 100.000 particles.

However, to allow for this current increase it seems that either a shorter focussing period should be provided in the first linac section, or the normal conducting DTL to SC transition should be raised to higher energies.

## *2.2 Reliability of the proposed design*

Having assessed that the basic design does not show serious limitations in achieving the objectives for a transmutation plant, we are now planning the inclusion of spare linac focussing cells in order to achieve full reliability in the case of klystron or cavity/coupler faults.

In spite of the demonstrated high reliability of the existing large scale superconducting RF accelerators (LEP, CEBAF, HERA and TRISTAN), a driver for a nuclear waste transmutation plant needs to satisfy the stringent requirements imposed by its specific use. In particular, a beam stop due to any failure of one of its components causes an interruption of the spallation neutron flux sustaining the subcritical system. If this interruption exceeds a fraction of an hour (the exact time depending on the details of the core design), the fuel bar poisoning rises: i.e. a new start up procedure needs to be performed and the waste cleaning process is partially lost.

For this reasons we are considering a linac design which includes two spare cryomodules for the low and intermediate energy sections. These two sections are the most critical, since they need to provide the correct transition energy to the following sections. A 10% spare contingency of three additional cryomodules is planned for the (less critical) high energy section. The lengthening due to the amount of contingency hardware is around 80 m, for a new total length of 800 m.

In the case of failure, a spare component will take the place of the faulty, and the beam will be back on the target in the time required by the reactor design. Some of the components, like the klystrons, could be repaired or replaced during the regular linac operation, while others, like the cavities or the RF couplers, will have to wait for the planned reactor maintenance shutdown.

The best use of these spare components when they are not needed (whether they are kept on or off at all times) needs to be analyzed on the basis of both capital and operational costs.

## 3 R&D ACTIVITIES ON THE SUPERCONDUCTING CAVITIES

The design of the three accelerating structures has been presented in detail at EPAC'98[4]. The geometry of a five cell cavity with an elliptical shape both at the iris and at the equator has been optimized in each linac section. The following design goals for the cavity operating conditions were chosen:

1. a peak surface electric field below 16 MV/m
2. a peak surface magnetic field below 40 mT
3. a good cell to cell coupling factor of 1.7%.

The cavities have been analyzed both with respect to the electromagnetic performances and with respect to the mechanical loads on the structures. Structural stiffening is required only for the lowest beta structure ($\beta$=0.5), and either a standard stiffening structure will be employed or a structural stiffening via copper spraying with a plasma jet (as proposed for the Tesla cavities[5]) will be performed.

Table 1 summarizes the main electromagnetic parameters of the TRASCO cavities, while Table 2 lists the geometrical parameters of the three structures. For an explanation of the symbols refer to the geometry sketched in Fig. 2.

The cavities will operate with an accelerating field of 4.6, 5.7 and 6.7 MV/m, respectively. A synchronous phase of 30 degrees has been chosen to provide the necessary longitudinal focusing.

Table 1: Main e.m. characteristics of the three structures.

| **$b_c$** | **$E_p/E_{acc}$** | **$B_p/E_{acc}$ [mT/MVm$^{-1}$]** | **Cell to cell coupling [%]** |
|---|---|---|---|
| 0.5 | 3.4 | 8.1 | 1.8 |
| 0.65 | 2.7 | 6.5 | 1.7 |
| 0.85 | 2.3 | 4.6 | 1.7 |

Table 2: Geometrical parameters (in mm) for the internal cell geometry, at the working cryogenic temperature.

| **$b_c$** | **0.5** | **0.65** | **0.85** |
|---|---|---|---|
| **A** | 47.1 | 71.6 | 131.3 |
| **B** | 80.1 | 121.8 | 196.9 |
| **a** | 33.4 | 44.8 | 35.4 |
| **b** | 60.1 | 89.6 | 56.7 |
| **d** | 26.8 | 32.8 | 26.8 |
| **L** | 101.1 | 132.6 | 175.7 |
| **D** | 392.2 | 392.7 | 385.2 |
| **$R_{iris}$** | 99.4 | 109.3 | 114.3 |

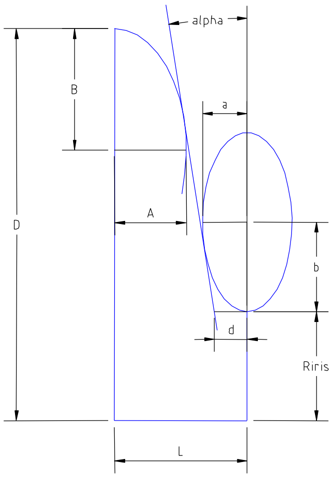


Figure 2: Reference geometry for the cavity shape.

### 3.1 *Cavity prototypes*

An agreement with CERN has been established in order to fabricate and test a full β=0.85 five cell cavity and a single cell test structure, on the basis of our design. The cavities will be ready for tests at CERN at the end of 98.

The Italian company Zanon will build a second β=0.85 cavity, a single cell Nb β=0.5 cavity and a complete copper model of the five cell structure. These additional cavities will be tested at CERN.

### 3.2 *High order modes and multipactoring*

An analysis of the high order modes distribution in the structure has been performed with the OSCAR2d code[6], showing modes with a very low R over Q. The choice of a beam tube diameter equal to the cavity inner irises helped in easing the behavior of the high order mode, since the field can freely propagate for any frequency above the tube cut-off. No trapped tube modes, like the ones measured on the LEP cavities, are possible.

Possible electron loading effects (multipactoring) were investigated, but the low magnetic fields and the elliptic shape of the equator resulted in a very safe cavity operation. In particular, the elliptical equator gives a stronger longitudinal component of the electric field along the surface, which pushes the electrons towards the equator, where the resonant condition for one point multipactoring is broken.

### 3.3 *Preliminary design of the cryomodules*

Based on the expertise gained in the design of the second and third generation of Tesla Test Facility cryostats we have started the design of the cryomodules for the superconducting linac. The design is still at a preliminary state, but various solutions have been chosen because of their success in the Tesla Test Facility design[7]. The cryostat will have a single thermal shield, made by self-sustained aluminum sheet or by a thin copper sheet kept by a stainless steel frame, and will be cooled by a finger welded pipe, to reduce production cost and assembling time. The cryomodule will be extremely modular, each module holding a single cavity in a titanium and stainless steel frame. The other guideline for the cryomodule design is a cost-effective solution, keeping in mind that extremely low thermal losses are not necessary when operating at 4.2 K. The vacuum vessel is open, similar to that one used in the LEP2, with a thin stainless steel sheet closing it, to guarantee easy access during the assembling and to reduce the assembling costs.

## 4 CONCLUSIONS

We have summarized here the status of the R&D activities for the TRASCO superconducting linac, aimed as a driver for nuclear waste transmutation and energetic applications. For sake of completeness we report in Table 3 an updated parameter list of the linac sections, where we explicitly indicated the necessary contingency for operational reliability.

Table 3: Summary of the SC TRASCO linac parameters.

| | SI | SII | SIII |
|---|---|---|---|
| **Section $b_c$** | 0.5 | 0.65 | 0.85 |
| **Section length [m]** | 96 | 146 | 475 |
| **Injection Energy [MeV]** | 100 | 190 | 428 |
| **Cell period [m]** | 8.0 | 11.2 | 15.3 |
| **# focussing cells/section** | 12+2 | 13+2 | 31+3 |
| **Max. DE/cavity [MeV]** | 4.0 | 6.5 | 10.0 |
| **$E_{acc}$ [MV/m]** | 4.6 | 5.7 | 6.7 |
| **# cavities/section** | 24 | 39 | 124 |
| **# cavities/cryomodule** | 2 | 3 | 4 |
| **# cryomodule/klystron** | 1 | 1 | 1 |
| **Beam power/cryom. [kW]** | 200 | 500 | 1000 |

The additional focusing cells indicated after the plus sign are the needed contingency required for the linac reliability

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