STATUS OF THE SARAF PROJECT

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Abstract

Soreq NRC initiated the establishment of SARAF – Soreq Applied Research Accelerator Facility. SARAF will be a multi-user facility for basic research (e.g. nuclear astrophysics, radioactive beams), medical and biological research, neutron based non-destructive testing (using a thermal neutron camera and a neutron diffractometer) and radio-pharmaceuticals research, development and production. SARAF is based on a continuous wave (CW), proton/deuteron RF superconducting linear accelerator with variable energy (5–40 MeV) and current (0.04-2 mA). SARAF is designed to enable hands-on maintenance, which implies beam loss below 10^{-5} for the entire accelerator. The commissioning of Phase I of SARAF (full current, energy up to 4-5 MeV) is taking place during 2006 at Soreq. Commissioning of the 40 MeV accelerator is foreseen during 2010.

PROJECT LAYOUT

The facility will consist of a medium energy (up to 40 MeV) high current (up to 2 mA) RF superconducting linac of protons and deuterons, beam lines and a target hall with several irradiation stations for the abovementioned applications.

The facility schematic layout is given in Fig. 1 and its required parameters are given in Table 1.

Due to the technical novelty in the accelerator, the project has been divided to two phases (Fig. 1). Phase I includes the ECR ion source, the RFQ, a prototype superconducting module (PSM), the design of the full accelerator (based on beam dynamics calculations [1]) and the design and risk reduction of the foreseen applications. Phase II includes construction of rest of the accelerator and its applications.

Table 1: SARAF design parameters

Ion species	p, d, q/A ≥ 2
Energy range	5 – 40 MeV
Energy adjustment accuracy	0.2 MeV
Current range	0.04 – 2 mA
Current adjustment accuracy	0.005 mA
Current stability (max current)	± 2.5%
Current structure	CW/macro-pulsed
linac frequency	176 MHz
Beam loss	< 1 nA/meter
Transverse emittance (norm, rms)	< 1 π·mm·mrad
Longitudinal emittance (rms)	< 4 nsec·keV/u
Operation hours per year	6000
Reliability	90%

This paper gives a technical description of the project components. For a review of its operation concept and control system see Ref. 2.

THE ACCELERATOR

The SARAF accelerator has been designed and is currently constructed by Accel Instruments GmbH. The design of the accelerator and its components was developed and optimized with extensive use of 3D tools for mechanics, heat transfer, RF and beam dynamics [3].

Ion Source and LEBT

The SARAF ion source is of type ECR, to ensure stable high quality performance and minimal maintenance. The ECR frequency is 2.45 GHz and the plasma is confined via two electromagnetic solenoids.

The ion source is followed by a low energy beam transport line (LEBT) which consists of three focusing solenoids, steerers, a bending magnet, which acts as an

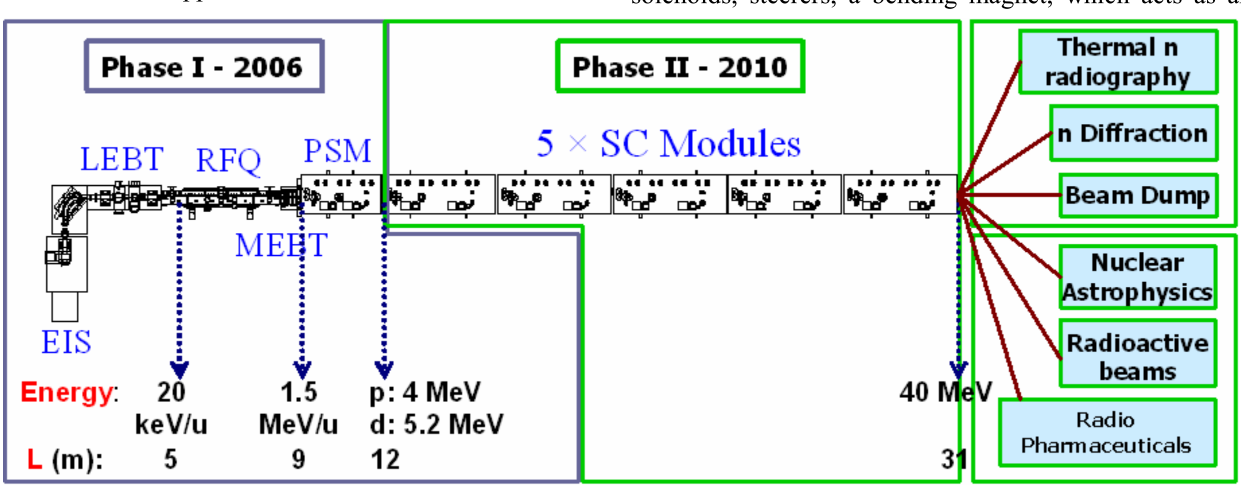

Figure 1: Schematic layout of SARAF. The architecture of the accelerator is displayed, including the length and ion energy at each stage. The division to Phase I and Phase II (including anticipated applications) is shown.

ion filter and beam diagnostics, which include two Faraday cups and a slit-wire system for emittance measurement (Fig. 2). Table 2 gives the main ion source parameters, where the beam parameters are measured at the LEBT exit.

Table 2: Ion source main design parameters

Ion species	p, d, H_2^+
Extraction Energy	20 keV/u
Energy ripple	±0.03 keV/u
Current range	0.04 – 5 mA
Current ripple (max current)	±2%
Emittance (norm, rms)	0.2 π·mm·mrad

The ion source has been built and commissioned at Accel premises. Of the main parameters, the energy, full current and required emittance has been fully achieved for protons and partly for H_2^+. Deuteron performance will be checked only at Soreq, where the site is equipped with the proper shielding and safety fixtures.

Figure 2: The ECR ion source (inside an HV cage) and the LEBT at Accel premises.

RFQ and MEBT

The SARAF RFQ is a 176 MHz 4-rod CW RFQ [4]. The main challenge in this RFQ is removing 220 kW from the ~3.8 meter rods (Table 3), an unprecedented heat density. A high flow water cooling system, including flow inside the rods has been incorporated in the RFQ. 3D heat transfer calculations show that heat induced distortion will be within the tolerance required to maintain the necessary deuteron beam quality.

Table 3: RFQ main design parameters

Output energy	1.5 MeV/u
Output energy spread	±0.03 MeV/u
Maximal current	4 mA
Transverse emittance (norm, rms)	0.3 π·mm·mrad
Longitudinal emittance (rms)	120 π·keV·deg/u
Transmission	90%
Length	3.8 meters
RF power (p,d)	55, 220 kW
Quality factor	2000

The RFQ is followed by a medium energy beam transport line (MEBT), which consists of three focusing quadrupoles (making the beam radially symmetric), steerers and beam diagnostics, which include a wire scanner, a phase probe and a beam position monitor. These diagnostics will enable non-destructive current measurement as well. Table 3 gives the main RFQ parameters, where the beam parameters are measured after the MEBT.

The RFQ has been installed at Soreq premises (Fig. 3) and commissioning is underway. Only low power operation was performed so far. The frequency was tuned, the electric field mapped and the quality factor was measured to be ~3600.

Figure 3: The RFQ as installed at Soreq. The 9” RF line, water pipes and vacuum pumps are also seen.

The RFQ power is delivered by a 9” RF coaxial pipe from the RFQ-RF system. This system, which is based on tetrode technology, has been installed and commissioned on site. It provided 300 kW at 176 MHz to a water cooled dummy load and all other system specifications were satisfied. Integration of the RFQ-RF with the accelerator low level RF (LLRF) system is still to be performed.

Prototype Superconducting Module

The prototype superconducting module (PSM) is described in detail elsewhere in these proceedings [5]. The PSM includes six 176 MHz, β=0.09 half wave resonators (HWR) made of bulk Nb and three superconducting solenoids inserted amongst them.

A total of seven HWRs have been produced and they have all performed above their required parameters (E_{peak} = 25 MV/m and Q = 4.7×10^8). All solenoids have been produced and tested as well. The PSM is currently being integrated at Accel towards factory commissioning.

RF power to each cavity is driven by a 2.4 kW solid state amplifier, all of which are controlled by the LLRF. The PSM-RF system has been factory commissioned and is currently being site commissioned.

Diagnostic Plate and Beam Dump

For characterizing the Phase I beam and then containing it, a diagnostic plate (D-Plate) and a beam dump have been designed and partially built. Their setup after the PSM is shown in Fig. 4.

The D-plate includes two phase probes for phase and TOF measurements, a current transformer, a beam

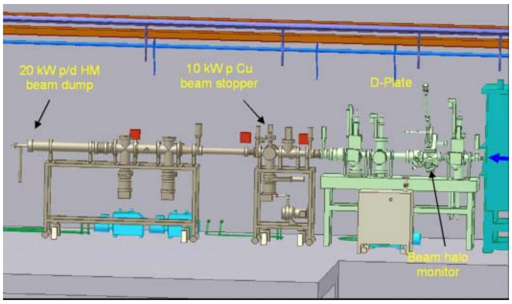

Figure 4: The D-plate and the two beam dumps as they are to be installed downstream of the PSM.

position monitor, an emittance slit and wire system, a fast faraday cup for bunch length measurement, a degrader and faraday cup system for measuring the energy spread and a beam halo monitor which is described in detail in [6]. The D-plate is designed to characterize the beam from the RFQ exit up to the 40 MeV linac.

The beam dump has a 10 kW Cu part suitable for the RFQ exit, and an additional Heavy Metal (HM) 20 kW part for the PSM. The length is designed to diffuse the beam density to the HM capability.

Phase II Linac

The current lattice design of Phase II includes five superconducting modules (SCM) (Fig. 1), each housing eight 176 MHz β=0.15 HWRs and four superconducting solenoids. However, recent beam dynamics calculations indicate that it may be beneficial to install six β=0.09 HWRs in the first SCM [1].

The space between the SCMs is planned for steerers and diagnostics that will enable operating the accelerator.

ACCELERATOR INFRASTRUCTURE

Cryogenics

The superconducting linac requires a LHe refrigerator to cool its components to 4.5K.

Table 4: Estimated sources of cryogenic losses

Source	Loss/Source	No. of Sources	Total
β=0.09 RF	10 W	6	60 W
β=0.15 RF	13 W	40	520 W
PSM Static	10 W	1	10 W
SCM Static	13.5 W	5	68 W
Total			658 W

To handle the SARAF cryogenic load (Table 4), two TCF 50 systems from Linde Kryotechnik are planned of which one was already commissioned on site for Phase I. The total refrigeration power will be 900 W at 4.5K and 1150 W at 70K for the cryostats shielding. At the cavities, the LHe pressure will be 1250 bar, with a stability requirement of ±1.5 mbar, to avoid microphonics.

Building

Currently, only a building for Phase I has been constructed, but it is part of a full design which will be completed upon the start of Phase II.

The accelerator is installed in a shielded corridor and on an isolated floor to diminish external microphonics (Fig. 5). Most of the service systems are in the service corridor behind shielding to minimize their radiation dose. The RF and cryogenic infrastructure is on the floor above and all penetrations are through the service corridors, to avoid direct line of sight to the accelerator. Additional aspects of this building are given in Ref. 2.

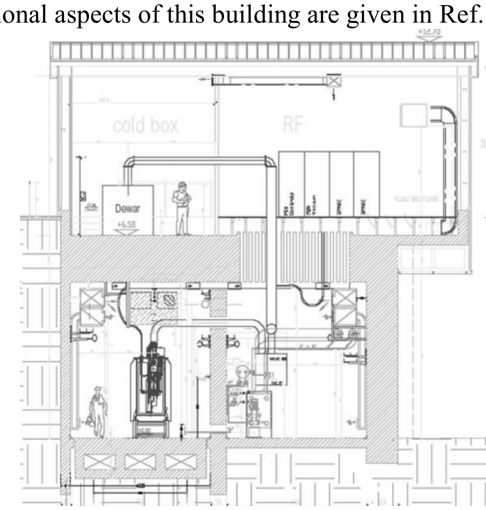

Figure 5: Cross section of the building including the beam and service corridors and the RF and cryogenics halls.

IRRADIATION TARGET COOLING

In order to use a 40 MeV, 2 mA beam, techniques for target heat removal (up to 80 kW on a few cm^2) are being developed at Soreq [7]. So far, heat removal of 5 kW/cm^2 and 3 kW/cm^2 has been achieved with jet impingement of water and liquid metal, respectively.

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