Radiological Protection Policy Aspects Concerning the Preliminary Design and Operation Modus of the Athens RT Microtron Facility

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The 185 MeV Racetrack Microtron under installation in the Athens Institute of Accelerating Systems and Applications has been developed in a joint NIST/LANL project [3], in order to cover the need for CW Electron Accelerators for nuclear physics.

The features of the NIST/LANL RTM allow the use of the accelerator to drive a FEL, as well as, a wide range of applications in irradiation techniques (e.g. material science, radiobiology etc.).

I. THE RACE-TRACK MICROTRON FEATURES

The 185 MeV Racetrack Microtron main parameters are following:

Injection energy	5 MeV
Energy gain per pass	12 MeV
Number of passes	1-15
Output energy	7-185 MeV
Average current	10-550 μA
Accelerating frequency	2380 MHz
End magnet field	1.0T
Peak current	< 65 mA
Micropulse length	3.5 psec
Micropulse frequency	2380 Mhz
Macroscopic duty factor	1.0
Energy spread	< 40 keV
Normalized emittance (βγε)	<10 μm

The accelerator comprises a 5 MeV Injector connected to a Racetrack Microtron by a 180 degree beam transport system. The Injector consists of an 100 keV, DC Electron Gun followed by a transverse emittance defining system, a Chopping and Bunching stage and a 5 MeV CW Linac.

In the RTM 5 MeV electrons from the Injector are recirculated for up to 15 passes through an 8 m long, 12 MeV, CW Linac for a total energy gain of up 180 MeV.

Microwave power is delivered from a single, 450 kW output cw Klystron (50 kW distribution system, 100 kW in the Injector Linac, 200 kW in the 12 MeV Linac.

The system uses 1.1 MW, of which 9% (100 kW) is converted into beam power [3]. With a floor area 5x16 m2 the RTM is extremely compact. The average beam power at full energy is 100 kW.

II. SITE PLANNING & RADIATION PROTECTION REQUIREMENTS

The Radiological Safety Aspects strongly influence the Site Planning. The major assumptions for the planning of the accelerator vault and the future extensions are following:

- The accelerator vault (9 x 36 m2, 7.5 m height) will be buried, taking into account the natural features of the ground.

- Bulky items should be brought into the vault through a concrete (cross section:4x4 m2) radiation protection door, moving on rails. Tracks are approaching through a ramp.

- The RTM will be installed in the first part (9 x 21 m2) of the vault. An experimental hall (9 x 14 m2) will be formed through a removable (equipment radiation protection) modular concrete 1 m thick and 2.5 - 3.0 m high wall, transported by a wall mounted 15 - 25 tn crane.

- At the end of the vault a beam dump and activation experiment space (6 x 3 m2, 3 m height) will be formed.

- The connection to the Auxilliary Building, which will include Control, Engineering, Laboratories etc., is done through a labyrinth, having a cross - section of 2 x 2 m2. Several shapes of the maze (two, three or four legged) have been examined.

- Cables and pipelines are guided through the maze, which will also enable personnel access and equipment transportation, on behalf of a lift and a staircase.

- The lay - out of the future extension of the IASA including fence - posting, as far as location and orientation is concerned, has been influenced by the shielding needs, since soil will be the main shielding material.

III. MAIN ASPECTS AND POTENTIAL HAZARDS ENCOUNTERED

Concerning radiological safety, following aspects, as well as, potential hazards have been mainly encountered:

- High-energy electron interactions with matter and estimation of the associated radiation parameters.

- Shielding calculations, interlocks and accesibility.

- Components, air, dust and cooling water activation.

- Radiolytic reactions and noxious gases formation.

- Hazards due to potential sources beyond ionizing radiations.

The starting points and the approaching technique are presented for the most important aspects:

A. Electromagnetic cascade.

High - energy electron interactions with matter lead to an estimation of the associated radiation parameters. Relevant for radiation protection purposes at the energy range up to 185 MeV are [11]:

- Secondary photons (Bremsstrahlung)

- Photoneutrons, i.e. giant resonance ($E < 30$ MeV), quasi-deuteron effect (30 MeV $< E <$ 140 MeV) and photopion channels opening ($E >$ 140 MeV).

B. Shielding calculation.

Shielding calculations have been based on the data of Alsmiller and Gabriel [1],[5]. Under the assumption of 2% lost power the first calculations result in following barriers thicknesses, taking into account possible future upgrading:

Structural Element	**Scheduled Construction**
Ceiling	2 m concrete + 4 m soil
Wall (Northern)	11 m soil
Wall (Southern)	10 m soil
Wall (Western)	8 m soil
Door	3 m concrete
Dump (walls)	13 m soil
Dump (ceiling)	12 m soil
Dump (beam-stop direction)	20 m soil

For the design of the maze connecting the accelerator vault and the auxilliary building, the thermal neutron transmission curves of Maerker et al. [8] have been taken into account.

The beam dump will be an Al cylinder [4], filled with Al spheres, fluted by cooling-water and followed by a Cu block.

The expected dose rate, due to neutron skyshine at different distances d from the facility, will be between:

0.5 nSv/h (d: 500 m) - 12 nSv/h (d: 100 m)
or
0.001 mSv/y - 0.024 mSv/y.

C. Radioactivation by the electron beam.

Radioactivity may be induced in solid components of the accelerator, as well as, in air contained in the accelerator vault, experimental halls etc. and in water of the cooling systems [2],[7]. The most important radioactivity-inducing reactions are the (γ,n) and much less the $(\gamma, 2n)$ ones.

The components to be most suspected for activation are those that absorb most of the beam energy, in particular the beam dumps, targets, magnets and collimators.

For the nuclides relevant for the radiation protection, the corresponding saturation activities [9],[10] are between 22 (Al) and 2000 GBq/kW (Stainless steel). The expected dose-equivalent rates, at 1 m distance from suspicious stainless steel components will not exceed, 0.30 mSv/h, at time of accelerator turnoff.

Activation monitors will be installed near the door (sluice) and other critical points.

The interaction of Bremsstrahlung with air nuclei causes mainly production of radioactive gases above the production threshold i.e. 10.55 MeV, due to giant resonance reactions. These interactions produce mainly O-15 and N-13 in air with 2.1 min and 10 min half-lives respectively [12].

For the facility, in the extreme case of having full power (185 MeV, 0.1 mA) on a high Z target the radioactivity production rate would be approximately 44.4 kBq/s and the corresponding equilibrium radioactivity 37 MBq.

Taking into account the dimensions of the accelerator vault the maximum concentration expected will be aproximately 0.0114 Bq/cm3, since the maximum permissible concentration (MPC) according to the ICRP Recommendation is 0.074 Bq/cm3.

Radioactivity in water is mainly formed by the interaction of Bremsstrahlung, with the O-16 component of, water-cooled targets and beam dumps, as well as in ground water, outside the concrete shielding and especially around the beam dump.

The maximal total saturation activity expected in the primary cooling system, taking into acount, that the maximum electron beam power will not exceed 18.5 kW, is expected to be 675 GBq, including 611 GBq of O-15, resulting in locally exposure rates of up to a few mSv/h which may easily be shielded. The ground water level seems to be much deeper than the critical 11 - 13 m from the surface.

Noxious gases produced by ionizing radiation are ozone (O-3) and nitrogen oxides (NOx). Ozone is the most toxic and might constitute a health hazard within the radiation room [13].

The saturation concentration of ozone, in the case of no ventilation is proportional to the effective decomposition time and the ozone production rate [6]. The expected saturation activity in the Microtron vault will be approximately five times less than the threshold limit value (0.1 ppm).

IV. ENVIRONMENTAL MONITORING PROGRAMME

Following measurement programme will be set up, in order to ensure an effective environmental monitoring:

- On line photon and neutron site monitoring (14 ionization chambers, several moderated BF-3 counters).

- Personnel and experimental site dosimetry (6LiF/7LiF albedo and polyethylene moderated dosemeters).

- Activation monitoring (locally survey meters, Ge - Multichannel Analyzer).

- Environmental monitoring and sampling system out of fence post.

- Background data aquisition.

A dedicated radiation protection and environmental monitoring laboratory will be provided in the auxilliary building of the Facility.

V. GENERAL SAFETY REQUIREMENTS.

Mechanical Hazards in the facility are related to the planninig, installation and operation of overhead cranes, load elevators, machine tools, gas bottles [11], compressed air etc. Further hazards are related with the design and the operation of the massive radiation protection doors and partitions or even with the installation of heavy items, as magnets. Last but not least, cooling water or water processing unit pipelines as well malfunction or inadequate planning in rain-water drainage, could result in flood and an appropriate detection and pumping system should be installed.

Electrical hazards include the ones due to high voltage used in the klystron, the vacuum and beam-line monitoring instrumentation, short-circuit hazards concerning the high current magnet power-supplies, as well as, the ordinary electrical hazads met in an industrial environment.

Disturbances caused by the high frequency on the RTM signal cables and monitoring equipment (e.g. to ionization chambers, if not RF-shielded), should also be considered.

Closely related to electrical hazards, is the threat of fireand the related fire-protection system of the facility including individual smoke detectors combined with Halon extinguishers, upon each major functional unit or ceiling mounted.

Finally, a general accident limitation operational policy, including all the remaining miscellaneous hazards (chemicals, toxic materials as lead, LASERS, intra-laboratory traffic etc.) should be worked out, on behalf of the architectural and functional features of the facility.

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