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RADIATION DOSIMETRY AT THE BNL MEDICAL RESEARCH REACTOR*

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DISCLAIMER

SUMMARY

The Medical Research Reactor, BMRR, at the Brookhaven National Laboratory, BNL, is a three megawatt, 3 MW, heterogeneous, tank-type, light water cooled and moderated, graphite reflected reactor, which was designed for biomedical studies, and became operational in 1959. It provides thermal and epithermal neutron beams suitable for research studies such as radiation therapy of various types of tumors. At the present time, the major program at BMRR is Boron Neutron Capture Therapy, BNCT.

BMRR has thermal and epithermal experimental treatment rooms on the west and east sides of the reactor. Three thimbles, cast in a concrete shield without shutters, are located on the north side. One of these is a radial beam thimble used to irradiate biological samples. One tangential thimble was used for experiments in neutron moderation but is currently blocked. The third thimble, having a pneumatic system (P_n tube) to convey samples to the edge of the graphite reflector zone, is used for radio-nuclide production and neutron activation analysis. In addition, there is a broad beam facility located at the end of the thermal column on the south side of the BMRR. It is five feet by five feet by three and one half feet deep and has been used for irradiation of large samples and large animals.

In recent years, the epithermal flux density has been enhanced by a series of changes to the BMRR. the shutter between the reactor core and the epithermal treatment room has been modified with the addition of aluminum and aluminum oxide to down scatter the fast neutrons into the electron-volt, eV, or low kilo-electron-volt, keV, energy range. In addition, the number of fuel elements has increased from 28 to 32 and four of the newer elements have been placed on the east side of the core facing the epithermal port. This has resulted in a 50% increase in the epithermal flux.

BNCT EXPERIENCE AT BNL

In 1936, Locher[1] proposed that medical research could be advanced by destroying cancerous cells using neutrons. He suggested the injection of a soluble, non-toxic compound of boron into superficial cancer followed by bombardment with slow neutrons, in order to liberate the ionization energy.

BNCT involves the minor stable nuclide of boron (^{10}B), which has an isotopic abundance of 19.8% and a cross section of 3838 x 10^{-24} cm^2 (barns) for absorbing a thermal neutron and emitting an alpha particle. ^4He with an energy of 1.47 MeV has a range of 10.1 μm (in water) and an average linear energy transfer, LET, of 150 keV/μm. The residual nucleus, ^7Li, with an energy of 0.85 MeV has a range of 4.9 μm and an average LET of 170 keV/μm. Due to the short range of both of these tracks, almost all of the energy is deposited within a cell diameter of where the reaction takes place. If the boron can be selectively targeted in a cancerous cell, only the cancerous cell would be destroyed, while nearby healthy cells would be relatively unaffected.

In clinical trials of BNCT in the 1950s and early 1960s, no technique was available that allowed prompt estimates of the patient's blood and/or tissue ^{10}B concentration to help plan the duration of the irradiation and total BNCT dose. Radiation damage to scalp became an early complication. Considerable variation existed from patient to patient in the ^{10}B concentration in their blood. An additional problem was due to the unavailability of boron containing compounds preferentially concentrating in tumors. No epithermal ports were available to provide adequate flux of thermal neutrons at depth. To minimize the absorption of thermal neutrons in tissues overlying the tumor, both the scalp and skull had to be temporarily reflected to directly expose the tumor to thermal neutrons. Recent modifications made to the BMRR core and shutter, mentioned above increased the flux of epithermal neutrons and now permits BNCT treatment for brain tumors without the need to reflect scalp and bone flaps. Clinical BNCT dose-escalation research protocols were initiated at the BMRR in September 1994. To date, a total of 38 patients with glioblastoma multiforme have received BNCT.

NEUTRON AND GAMMA RAY DOSIMETRY

In conjunction with the BNCT treatment, extensive measurements and calculations have been performed in both the epithermal and the thermal treatment rooms to characterize the neutron and gamma ray flux density and dose rate. Bare and cadmium covered gold foils, as well as various threshold detector foils, bare and polyethylene covered thermoluminescent dosimeters, TLDs, and test badges with both ^{6}LiF and ^{7}LiF chips have been utilized to provide experimental data on the thermal and epithermal neutron flux densities, the thermal and fast neutron dose rates and gamma ray dose rates. At the same time, Monte Carlo calculations of the neutron energy spectra and flux densities from thermal (0.01-0.4 eV) up to fast (0.1-10. MeV) neutron energies and gamma rays have been performed to provide energy dependent distributions at various locations throughout the epithermal and thermal treatment rooms. The program MCNP[2] has been used to mock up the geometry of the core, reflector and the epithermal port and thermal port construction and collimators. Comparison have been made with the patient in place, with a tissue equivalent head phantom in place to mock up the patient and with the room empty to study the impact of the patient on the background fluxes and dose rates in the epithermal treatment room.

It was previously noted[3] that the gamma-ray dose rate received by staff personnel during the treatment of the first twelve BNCT patients averaged between 1.4 millirem to 3.2 millirem per person.

DOSIMETRY RESULTS

The neutron flux densities at various locations at the BMRR have been measured and calculated to be 10^7 thermal neutrons/cm^2/sec and 10^8 epithermal neutrons/cm^2/sec and 10^7 fast neutrons/cm^2/sec at the beam center in the epithermal room. In the thermal treatment room, the values have been determined to be 10^{10} thermal neutrons/cm^2/sec and 10^9 epithermal neutrons/cm^2/sec and 10^8 fast neutrons/cm^2/sec at the beam center. There is agreement between the MCNP calculations and the various bare foil and cadmium covered foil measurements.

Preliminary data in the epithermal treatment room indicate that the neutron dose rate falls off rapidly as you move out from the center of the beam. There is a reduction in the neutron dose rate at the reactor face by a factor of 5 to 10 in all directions at a distance of two feet from the beam center. Although there is some neutron scattering back from the patient to the face of the reactor, there appears to be more back scattering of gamma radiation to the face of the reactor. Although there is a significant reduction in the neutron dose rate on the wall directly opposite the patient, there appears to be little change in the gamma-ray dose rate. This would indicate that there is much more absorption of neutrons than gamma-radiation by the patient, which is the preferred situation.

CONCLUSIONS

Modifications have been made to the BMRR to significantly increase the available epithermal neutron flux density to a patient in clinical trials of BNCT. The above data indicate that the flux density and dose rate are concentrated in the center of the beam, the patient absorbs neutrons rather than gamma radiation and as noted previously even with the increasing flux values, gamma-ray dose received by the attending personnel has remained minimal. Flux densities in the center of the thermal port and epithermal port beams have been characterized with an agreement between the measurements and the calculations.

REFERENCES

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