COMPUTER AIDED DESIGN OF FAST NEUTRON THERAPY UNITS

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During the last decade several radiotherapy centers all over the world used fast neutrons with considerable success to treat certain types of cancer. Randomized clinical studies have shown that at least some groups of cancer respond better to fast neutrons than to megavoltage X-ray therapy. Correspondingly, there exists a strong demand to develop and to construct more and better fast neutron therapy machines to make this therapeutic modality available to more patients.

In an effort to help meet this continuously increasing demand and at the same time to reduce design costs significantly, a novel approach has been used at KMS Fusion, Inc. laboratories: A computer code, TBEAM, has been developed that can determine the physical characteristics of the neutron beam generated in a machine of given geometric configuration and materials' composition.

Neutron flux, energy flux, spectral composition of the incident beam, collimation and shielding efficiency, activity induced by the interaction of fast neutrons with various components of the equipment are among the design parameters determined by TBEAM. These and several other parameters indispensible to the evaluation of patient dose, scattered dose, occupational exposure of personnel are furnished by TBEAM, without the cost and effort involved in the actual construction of a candidate design. By the same token, TBEAM is eminently applicable to parametric studies as well as to comparison of the effects of various construction materials and geometric configurations used in candidate designs, and thus to optimization of design.

Required physical characteristics of the beam are to be determined by criteria set by the clinician. To be therapeutically useful, the fast neutron beam should have sufficient penetration to treat deepseated tumors, the biological shielding of the facility should protect personnel and patients. Collimation should be adjustable so as to restrict the beam to the size of the area to be treated, i.e., the penumbra around the edges of the beam resulting from stray radiation between the treated and shielded zones should be high. Beam intensity should be sufficient to permit relatively short treatment times. Induced radioactivity in various components should be shortlived to avoid both long waiting times between treatments and potential occupational hazards to the operating personnel. Neutron beams with narrow spectral width are conducive to faster, more accurate dosimetry.

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It appears that due to its unique space, time and energy characteristics, a neutron source generated by laser fusion could be used in a therapeutic facility with considerable advantages. Such a source, being monoenergetic at 14.1 MeV, has approximately the same penetration as Co^{60} gamma rays; being a point source collimation is simplified; and since the neutrons are delivered in very short bursts, the dose can be spread over several pulses spaced into time so that the integrated dose, in a given treatment session, can be accurately controlled.

A typical treatment schedule of 1560 rads, administered in 12 sessions requires 130 rads per session. Assuming a source-skin distance of 120 cm, and emission of 4×10^{14} neutrons at 14.1 MeV in each pulse, the average dose absorbed by a superficial tissue layer facing the incident beam is approximately 18.35 rads per pulse. Two pulses per minute would provide a convenient 3 - 4 minute irradiation time per session.

Laser fusion experiments are being performed at several laboratories on a routine basis. There is considerable experience at hand that is applicable to the development of a therapeutic facility that could satisfy all design criteria dictated by clinical considerations. Conceptual design of a therapeutic facility of this kind is under consideration at KMS Fusion, Inc.

The basic mechanical design of such a fast neutron therapy unit would consist of a spherical shell-shaped shielding structure at the center of which is located the point source of fusion neutrons. The therapeutically useful beam exits through a conically shaped collimating aperture. The opening angle of the collimator could be varied, according to instructions of the therapist by insertion or removal of appropriately shaped collimator liners. Should it prove necessary, remote control of collimator placement can be used to protect the operator from excess exposure to radioactivity that might have been generated due to previous exposure of structural components to the neutron field.

No attempt is made here to describe details concerning the optical path of the laser beam nor the fuel (pellet) injection mechanism, although these problems are being considered. The patient to be treated could be positioned as comfortably as possible on a bed-like treatment table and could be rotated isocentrically around the source if the clinical situation thus requires.

TBEAM has been developed as part of the effort toward a viable conceptual design. The input file of TBEAM contains, among others, the following design data describing the facility: relative configuration of source, shield, collimator and irradiated area, materials' composition of the shield collimator assembly and of related components, source strength, source geometry and possibly other parameters of the facility. Materials' composition data are entered as appropriate number densities. "One Hundred Group Neutron Reaction Cross Section Data Generated by SUPERTOG from ENDF/B" (published by ORNL-RSIC. DLC-24) is used as cross section input file.

TBEAM uses the method of statistical sampling (Monte Carlo) to solve the space, time and energy dependent neutron transport equation associated with the configuration and materials' composition of the design specified by the design engineer. The code traces the individual source neutrons as they propagate throughout the shield collimator assembly and determines the energy and the position of each neutron at the instance of incidence. Those results, in turn, serve as input to a set of subroutines which compute spatial flux distribution, activation and spectral distribution, as requested by the user. The TBEAM library also contains a graphical package that puts out diagrams of spectral composition, incident flux vs position, energy flux vs position, and also a multicolored diagram of neutron traces, labeling points of incidence of uncollided and of scattered neutrons on the various regions with differently colored symbols.

Comparison of TBEAM generated narrow beam attenuation results show good agreement with published measured data. The TBEAM design code, due to its built-in flexibility, can accommodate energy deposition in homogeneous and heterogeneous media including such heterogeneous phantoms as, e.g., the standard reference man, along with the isodose curves required in treatment planning.

To make TBEAM applicable to accelerator or cyclotron driven fast neutron machines, an option has been included to deal not only with point shaped, but also with plate shaped sources; not only with monoenergetic sources, but also with sources of any given spectral composition. In a sample problem, the results of which are presented in Table 1, TBEAM has been used to compare physical characteristics of fast neutron beams emitted from two facilities having identical design except for the source geometry which was a point in Case A and a circular plate in Case B.

Results of the sample problem and of various other design studies performed with TBEAM, favor the point neutron source generated in laser. Fusion. They suggest that, with all other design characteristics being identical, the point source compared to a plate source generates a beam having a harder incident spectrum on the field of irradiation (conducive to better penetration); better collimation (i.e., penumbra/umbra contrast); better shielding (i.e., less scattered and leakage energy flux per unit energy flux on target and a softer spectrum of the scattered and leakage flux).

Table 1. COMPARISON OF PHYSICAL CHARACTERISTICS OF FAST NEUTRON BEAM A (POINT SOURCE) VS BEAM B (PLATE SOURCE)

	CASE A Point Source	CASE B Plate Source
Relative Energy Flux Incident on Field of Irradiation	192 :	100
Fraction of 14.1 MeV Neutrons in Total Number Flux Incident on Field of Irradiation	85:100	72:100
Ratio of Energy Flux Incident on First Penumbra vs That on Field of Irradiation	1.7:100	10:100
Ratio of Energy Flux Incident on Second Penumbra vs That on Field of Irradiation	0.17:100	4:100
Ratio of Energy Flux Incident on the Total Body Area vs That Incident on Field of Irradiation	0.07:100	83:100

The above example is meant to illustrate the capacity of TBEAM to evaluate and compare a wide variety of candidate designs at a fraction of the cost that would be involved in actual construction and experimental testing.