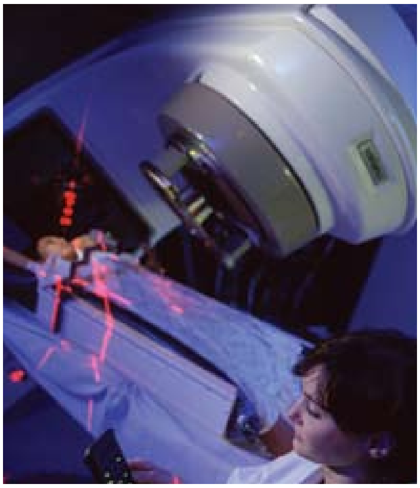



# Do proton radiotherapy collimators pose neutron radiation risks?

Bryant Furlow

Tungsten-alloy multileaf collimator (MLC) technology, borrowed from traditional external-beam radiotherapies, promises to reduce costs and delivery times for proton beam therapy, an emerging dose-escalated treatment for tumor control. But a new computer modeling study from the Indiana University Health Proton Therapy Center raises concerns about potential secondary and residual neutron radiation doses—particularly to staff—generated by tungsten's interactions with proton fields. *Oncology Nurse Advisor* spoke with a senior author of that study and critics who say real-world proton therapy is much safer than the Indiana University study suggests.

## PROTON BEAM RADIOTHERAPY

The tumor-killing radiation doses that can be delivered via traditional external-beam photon or gamma radiotherapy have long been limited by patient morbidity associated with the irradiation of healthy tissues. The promise of proton beam radiotherapy stems from protons' dose distributions, which allow more precisely targeted, escalated-dose irradiation of tumor tissues while reducing doses to nontarget tissues. The large mass of charged particlelike protons reduces beam broadening and side scatter along beam pathways compared with that seen with other external-beam radiotherapies, for example. And along beam paths, protons' Bragg peak distributions are very narrow, delivering very little radiation to skin at the beam-entrance site or tissues behind or below target tissue.[1]

Those dose distributions offer an appealing alternative to other modalities, particularly, it has been argued, for children or young adults, for whom secondary cancers are a significant concern.[1-3] But proton therapy facilities are expensive, with initial set-up costs of approximately $225 million.[2] Patient-specific beam-shaping brass apertures used in proton therapy also drive up costs—up to $2,550 per aperture.[3]

## MULTILEAF COLLIMATORS SAVE TIME AND MONEY

An intuitively attractive cost-control measure for proton therapy has been to sidestep the use of expensive and labor-intensive brass apertures by modifying tungsten multileaf collimators (MLCs) already widely employed for intensity modulated radiation therapy (IMRT) and 3-dimensional conformal radiotherapy (3DCRT).[3] MLCs allow a set of adjustable leafs to easily reshape radiation beams to patient-specific plans. Developed in the 1990s to replace cerrobend blocks, MLCs dramatically simplified IMRT radiotherapy workflows.

Unfortunately, proton beam interactions with field-modifying equipment (including MLCs, double-scattering systems, and range compensators) produce secondary neutron radiation exposures, raising concerns about potential secondary cancer risks.[3-6] The long-term effects of secondary neutron radiation have been little-studied, and the risks of low-dose neutron irradiation remain poorly understood.[7]

## SECONDARY AND RESIDUAL NEUTRON IRRADIATION

Now, a complex computer-modeling study published in the December 2011 issue of *Medical Physics* suggests the resulting ambient neutron radiation doses could reach 100 μSv per hour on the patient's side of the proton beam collimator and 27 times higher than that upstream of MLCs. The team's model predicts secondary neutron doses to patients to be at least 1.5 times higher when tungsten MLCs are used than will be the case with brass apertures, and the upstream ambient radiation dose to be 220 times higher for tungsten than brass.[3]

What's more, the team found the buildup of residual neutron activity induced by proton fields is much steeper over time for tungsten than brass, requiring prolonged storage for activity cooling.[3] That could become a significant occupational-exposure issue at centers with large patient populations, according to the study's authors at Indiana University School of Medicine and the Indiana University Health Proton Therapy Center (formerly the Midwest Proton Radiotherapy Institute) in Bloomington.

Although based on a worst-case scenario of a fully closed tungsten MLC, these predicted doses could lead to an accumulated dose for radiotherapy staff that may exceed the occupational maximum permissible dose of 50 µSv/yr, the authors concluded.[3] "The transfer of the tungsten MLC technology from megavoltage photon beams to proton therapy should be carefully examined in the context of secondary neutron yield from the collimator and associated secondary cancer risk," the team reports.[3] "Usage of tungsten MLC in [the proton beam therapy] clinic may create unnecessary risks associated with secondary neutrons and induced radioactivity for patients and staff, depending on patient load."

Neutron dose associated with proton field irradiation of tungsten is not a new concern. Two 2009 studies suggested tungsten yields higher neutron doses than brass. One of these studies reported neutron doses to be higher with tungsten than apertures made of any other material studied—cerrobend, brass, iron, or nickel.[8] The other 2009 study found a tungsten MLC to yield up to twice the neutron dose of brass collimators.[9] (However, a third study published the same year found tungsten collimators in a double-scattering proton unit to *reduce* secondary neutron doses compared with those associated with brass.[10])

There is "very little staff can do" about the predicted ambient neutron radiation dose, according to coauthor Indra J. Das, PhD, Director of Medical Physics for Indiana University's Department of Radiation Oncology and the Indiana University Health Proton Therapy Center. "It is the poor selection of material," Das told *Oncology Nurse Advisor.* "When designing MLC, one has to choose low atomic number materials."

But critics believe the Indiana University model's results overstate the risks of using tungsten MLCs with proton therapy. "Unwanted neutron dose to the patient has been the subject of countless articles but is greatly overblown," proton therapy physicist Bernard Gottschalk, PhD, of Harvard University's Laboratory for Particle Physics and Cosmology told *Oncology Nurse Advisor.* "The lifetime risk of a fatal cancer from these neutrons is very poorly known but is thought to be less than 1%. In the vast majority of cases, depending on the shape and depth of the tumor, the main unwanted dose in proton therapy is not from neutrons. It is from *protons*. Residual radioactivity is even less of an issue."

## The main unwanted dose in proton therapy is not from neutrons.

Real-world surveillance of neutron radiation doses to staff at the University of Pennsylvania's proton therapy unit—which uses a tungsten-alloy MLC—do not support the Indiana University model's predictions, according to Richard L. Maughan, PhD, Director & Clinical Chief of Medical Physics at the University of Pennsylvania's Division of Medical Physics. "[Staff] wear monitoring film badges constantly and they're sent away every 3 months," Maughan said. "We've never seen a reading from any of the badges." The badges have a detection threshold of 100 µSv (500 times lower than the occupational maximum permissible dose).

A study by Maughan's team, published in the November 2011 issue of *Medical Physics,* found "nearly equivalent" neutron production in a practical tungsten alloy MLC and brass-block apertures used with proton therapy, even under the "overly pessimistic" worst-case scenarios described in the Indiana model involving a completely closed MLC.[7] "The [Indiana] study is a Monte Carlo model, all calculations," Maughan told *Oncology Nurse Advisor.* "It's just modeling. We actually have four tungsten MLCs we use in proton therapy." The University of Pennsylvania data are based on practical measurements.

Upstream areas close to the MLC should be inaccessible during neutron production, Maughan notes. "Neutron production is only occurring while the proton [unit] is on, so [staff] is not going to be in the room. It's not going to affect staff because they're never in the room when the beam's on."

When Maughan worked with neutron therapy, in contrast, staff did get film badge readings and had to be rotated through the room to avoid excessive radiation doses. "The collimator in a neutron facility becomes very activated," he said. "But even with 2,000 times the neutrons, as seen in proton therapy, you can safely operate neutron facilities. For the production of radiation from residual activation, it really isn't an issue whether you use tungsten or brass collimators with proton therapy.... The excess radiation to the patient from residual radiation is negligible compared to the dose from scattered protons and neutrons. Activation is an issue for staff. As the MLC is a fixed device, the staff never come in close contact with the activated material; brass apertures must be carried by the staff in close proximity to their bodies immediately after irradiation which may lead to higher exposures,

[but] no proton therapist at any center, to my knowledge, has recorded any [badge] reading."

Maughan readily admits tungsten yields more neutrons than brass, but the greater attenuation provided by the MLC leafs reduces the neutron dose to the patient. He further explains that from a mechanical point of view brass may not be a good material for high-precision MLCs. "The [MLC] gaps are small," Maughan said. "Tungsten is very stable. Brass is comparatively not very stable. If you take a flat piece of material 5 mm thick or less, with brass, you can get a nice flat plate but once you machine it, there are stresses in brass and warping. With the intricacies you need in a collimator leaf, such tight tolerances of a few thousandths of an inch, the warping causes the plates to move together resulting in potential mechanical 'jamming' and failure." ■

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