The Dosimetric And Radiobiological Impact Of Calculation


The US Environmental Agency Office of Radiation and Indoor Air asked the National Research Council to evaluate whether sufficient new data exist to warrant a reassessment of health risks reported in Health Effects of Exposure to Low Levels of Ionizing Radiations (BEIR V) in 1990. To respond to this request, the National Research Council assembled the Committee on Health Risks of Exposure to Low Levels of Ionizing Radiations. The work of the committee was conducted in what was called the BEIR VII phase-1 study. To assist the committee during its deliberations, various scientists were consulted for advice, and a workshop on the impact of biology on risk assessment was held in collaboration with the Department of Energy Office of Health and Environmental Research. The intent of the workshop was to address the implications of new understanding of the biologic basis of radiation injury and carcinogenesis for risk assessment.

Purpose: To evaluate the dosimetric and radiobiological impact of PB algorithm versus MC algorithm in intensity-modulated proton therapy (IMPT) plans for breast cancer treatment. Methods: 20 breast cancer patients who received IMPT to the breast/chest wall and regional lymphatics were included in this study. For each patient, 2 IMPT plans were generated: a PB-optimized plan and a MC-optimized plan. The radiobiological and dosimetric impact of the dose algorithms was assessed. The Poisson Linear-Quadratic model was used to estimate the tumor control probability (TCP). The influence of the model parameter uncertainties on the TCP was tested against different sets of published model parameters. Results: The PB-optimized plans significantly under-dosed the target as compared to the MC-optimized plans. The median (range) differences in CTV D95% and CTV Dmean were 3.8% (2.4% - 6.2%) and 2.4% (1.0% - 3.8%) of the prescription dose. The TCP was lower in the PB-optimized plans than the MC-optimized plans. The median (range) of the TCP differences (uf044TCP) were 4% (2% - 6%), 3% (2% - 5%), and 2% (1% - 3%), respectively, when calculated using 3 different model parameter sets. The uf044TCP correlated with the CTV dose difference, and moderately correlated with the CTV volume. Conclusion: Due to the inaccurate dose modeling, PB-optimized plans under-dose the target and therefore yield a lower TCP compared to MC-optimized plans in breast IMPT. The magnitude of the resulting difference in TCP reached 6% in our study.

Successful clinical use of intensity-modulated radiation therapy (IMRT) represents a significant advance in radiation oncology. Because IMRT can deliver high-dose radiation to a target with a reduced dose to the surrounding organs, it can improve the local control rate and reduce toxicities associated with radiation therapy. Since IMRT began being used in the mid-1990s, a large volume of clinical evidence of the advantages of IMRT has been collected. However, treatment planning and quality assurance (QA) of IMRT are complicated and difficult for the clinician and the medical physicist. This book, by authors renowned for their expertise in their fields, provides cumulative clinical evidence and appropriate techniques for IMRT for the clinician and the physicist. Part I deals with the foundations and techniques, history, principles, QA, treatment planning, radiobiology and related aspects of IMRT.
clinical applications with several case studies, describing contouring and dose distribution with clinical results along with descriptions of indications and a review of clinical evidence for each tumor site. The information presented in this book serves as a valuable resource for the practicing clinician and physicist.

Radioembolization is a widely used treatment for non-resectable primary and secondary liver cancer. This handbook addresses the radiation biology, physics, nuclear medicine, and imaging for radioembolization using Yttrium-90 (90Y) microspheres, in addition to discussing aspects related to interventional radiology. The contents reflect on and off-label treatment indications, dose-response relationships, treatment-planning, therapy optimization, radiation safety, imaging follow-up and many other facets of this therapy necessary for both novice and advanced users alike.

Imaging is a critical component of the management of patients having radiotherapy. This book covers the basic principles of the main imaging modalities; site specific chapters give best practice for individual tumour sites, and it also contains information on radioprotection and regulatory issues.

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An ideal text for radiation oncologists, hematologist-oncologists, and radiologists, Image-Guided Radiotherapy and Functional Imaging in Modern Lymphoma Management is the foremost source for information on the increasingly important subject of image guided radiation therapy (IGRT) and its crucial role in the clinical evolution of high-precision ionizing beam therapy. An understanding of IGRT allows clinicians to improve targeting accuracy and safely increase dosage administration without increasing toxicity in normal, healthy tissue areas, resulting in better lymphoma patient outcomes.

This book provides a first authoritative text on radiochromic film, covering the basic principles, technology advances, practical methods, and applications. It focuses on practical uses of radiochromic film in radiation dosimetry for diagnostic x-rays, brachytherapy, radiosurgery, external beam therapies (photon, electron, protons), stereotactic body radiotherapy, intensity-modulated radiotherapy, and other emerging radiation technologies. The expert authors address basic concepts, advantages, and the main applications including kilovoltage, brachytherapy, megavoltage, electron beam, proton beam, skin dose, in vivo dosimetry, postal and clinical trial dosimetry. The final chapters discuss the state of the art in microbeam, synchrotron radiation, and ultraviolet radiation dosimetry.

This text is a concise handbook designed to assist the clinician in the implementation of Accelerated Partial Breast Irradiation (APBI). It includes a review of the principles that underlie APBI, a practical and detailed description of each technique for APBI, a review of current clinical results of APBI, and a review of the incidence and management of treatment related complications. The book encompasses a number of different techniques and approaches that include brachytherapy, intraoperative, and external beam techniques. There is currently no single source that describes these techniques and their clinical implementation.

It is probably only a matter of time before we witness the next event in which large numbers of people are exposed to ionizing radiation. In the past, planning a response to such an occurrence would have likely focused on the management of casualties from high-dose exposure. However, more recently, a different threat has come to the fore: accidental (through a containment breach in a nuclear power plant, for example) or intentional (via a "dirty bomb") releases of radioactivity resulting in low-dose exposure to a population. The magnitude of the health risks arising from low-dose radiation exposure is uncertain, and this uncertainty has significant economic implications for public health decision making. "Research on Health Effects of Low-Level Ionizing Radiation Exposure" examines recent scientific knowledge about the human effects of exposure to low-dose radiation from medical, occupational, and
environmental ionizing-radiation sources. This report is intended to provide advice to the Armed Forces Radiobiology Research Institute (AFRRI) about its role in low-dose radiation health effects research. The report identifies current research directions in radiobiological science and assesses how AFRRI programs are advancing research along these directions. The recommendations of "Research on Health Effects of Low-Level Ionizing Radiation Exposure" will provide guidance for AFRRI to build on its strengths and advance its mission while contributing to the body of scientific knowledge on the health effects of exposure to low-dose ionizing radiation.

This volume is based on the proceedings of an Advanced Study Institute (ASI) sponsored by the North Atlantic Treaty Organization (NATO) held October 1987 in Corfu, Greece. The Institute received financial support from the National Aeronautics and Space Administration, U.S.A. Armed Forces Radiobiology Research Institute, U.S.A. Department of Energy, U.S.A. Deutsche Forschungs-und Versuchanstalt fur Luft und Raumfahrt e.v., Kaln, Germany The advent of the shuttle era is providing fresh impetus for large space ventures such as communication centers, solar power stations, astronomical observatories, orbiting factories, and space based radar. Such ventures will rely heavily on an extensive and prolonged human presence in space doing in-orbit construction, maintenance, and operation. Among the advantages of location in space are the near zero gravity environment, commanding location, and the reception of solar energy and astronomical signals unattenuated by the atmosphere. Central to long-term manned space missions are the problems associated with the effects of exposure to ionizing radiations on humans. Manned space m ission s in the past have encountered relatively benign radiation en vironments because of their very short duration and orbit configuration. However, crew stay time of up to a year has been recently achieved by the Soviet space program; and Mars missions lasting several years are under serious consideration.

Comprehensive Biomedical Physics is a new reference work that provides the first point of entry to the literature for all scientists interested in biomedical physics. It is of particularly use for graduate and postgraduate students in the areas of medical biophysics. This Work is indispensable to all serious readers in this interdisciplinary area where physics is applied in medicine and biology. Written by leading scientists who have evaluated and summarized the most important methods, principles, technologies and data within the field, Comprehensive Biomedical Physics is a vital addition to the reference libraries of those working within the areas of medical imaging, radiation sources, detectors, biology, safety and therapy, physiology, and pharmacology as well as in the treatment of different clinical conditions and bioinformatics. This Work will be valuable to students working in all aspect of medical biophysics, including medical imaging and biomedical radiation science and therapy, physiology, pharmacology and treatment of clinical conditions and bioinformatics. The most comprehensive work on biomedical physics ever published Covers one of the fastest growing areas in the physical sciences, including interdisciplinary areas ranging from advanced nuclear physics and quantum mechanics through mathematics to molecular biology and medicine Contains 1800 illustrations, all in full color

This publication is aimed at students and teachers involved in teaching programmes in field of medical radiation physics, and it covers the basic medical physics knowledge required in the form of a syllabus for modern radiation oncology. The information will be useful to those preparing for professional certification exams in radiation oncology, medical physics, dosimetry or radiotherapy technology.

Written by internationally known experts in the field, Stereotactic Radiosurgery and Stereotactic Body Radiation Therapy examines one of the fastest-developing subspecialties within radiation oncology. These procedures deliver large doses of radiation in one to five sessions to a precisely determined target. Often these techniques have proven to be as or more effective than traditional radiation therapy techniques, while at the same time being cost-efficient and convenient for the patient. These techniques, however, require careful planning, specialized equipment, and well-trained staff. This volume provides a cutting-edge look at the biological and technical underpinnings of SRS and SBRT techniques. It includes a history of the development of SRS and SBRT; clinical applications of the techniques; dedicated devices for delivering precisely shaped, high doses of radiation; use of in-room imaging for treatment planning and treatment guidance; immobilization techniques for accurate targeting; and future developments that will continue to evolve and refine existing techniques. A valuable introduction to those just learning about these specialized techniques, and an ideal reference for those who are already implementing them, this book covers a wide variety of topics, with clear discussions of each aspect of the technology employed.

Clinical conformal radiotherapy is the holy grail of radiation treatment and is now becoming a reality through the combined efforts of physical scientists and engineers, who have improved the physical basis of radiotherapy, and the interest and concern of imaginative radiotherapists and radiographers. Intensity-Modulated Radiation Therapy describes in detail the physics germane to the development of a particular form of clinical conformal radiotherapy called intensity modulated radiation therapy (IMRT). IMRT has become a topic of tremendous importance in recent
years and is now being seriously investigated for its potential to improve the outcome of radiation therapy. The book collates the state-of-the-art literature together with the author’s personal research experience and that of colleagues in the field to produce a text suitable for new research workers, Ph.D. students, and practicing radiation physicists that require a thorough introduction to IMRT. Fully illustrated, indexed, and referenced, the book has been prepared in a form suitable for supporting a teaching course.

Over the last 4 years, IMRT, IGRT, SBRT: Advances in the Treatment Planning and Delivery of Radiotherapy has become a standard reference in the field. During this time, however, significant progress in high-precision technologies for the planning and delivery of radiotherapy in cancer treatment has called for a second edition to include these new developments. Thoroughly updated and extended, this new edition offers a comprehensive guide and overview of these new technologies and the many clinical treatment programs that bring them into practical use. Advances in intensity-modulated radiotherapy (IMRT), and 4D and adaptive treatment planning are clearly presented. Target localization and image-guided radiotherapy (IGRT) systems are comprehensively reviewed as well. Clinical tutorials illustrate target definitions for the major cancer sites, and useful techniques for organ motion management are described and compared. There are also several chapters that explore the technical basis and latest clinical experience with stereotactic body radiotherapy (SBRT) and summarize practical treatment recommendations. Furthermore, the significant and increasing contributions of proton therapy to cancer care are also highlighted, alongside the practical allocation of all these new technologies from an economic perspective. As a highlight of this volume, a number of images can be viewed online in time-elapse videos for greater clarity and more dynamic visualization. Written by leading authorities in the field, this comprehensive volume brings clinical and technical practitioners of radiotherapy fully up to date with the key developments in equipment, technologies and treatment guidelines.

Modern medical imaging and radiation therapy technologies are so complex and computer driven that it is difficult for physicians and technologists to know exactly what is happening at the point-of-care. Medical physicists responsible for filling this gap in knowledge must stay abreast of the latest advances at the intersection of medical imaging and radiation therapy. This book provides medical physicists and radiation oncologists current and relevant information on Adaptive Radiation Therapy (ART), a state-of-the-art approach that uses a feedback process to account for patient-specific anatomic and/or biological changes, thus delivering highly individualized radiation therapy for cancer patients. The book should also benefit medical dosimetrists and radiation therapists. Adaptive Radiation Therapy describes technological and methodological advances in the field of ART, as well as initial clinical experiences using ART for selected anatomic sites. Divided into three sections (radiobiological basis, current technologies, and clinical applications), the book covers: Morphological and biological biomarkers for patient-specific planning Design and optimization of treatment plans Delivery of IMRT and IGRT intervention methodologies of ART Management of intrafraction variations, particularly with respiratory motion Quality assurance needed to ensure the safe delivery of ART ART applications in several common cancer types / anatomic sites The technology and methodology for ART have advanced significantly in the last few years and accumulated clinical data have demonstrated the need for ART in clinical settings, assisted by the wide application of intensity modulated radiation therapy (IMRT) and image-guided radiation therapy (IGRT). This book shows the real potential for supplying every patient with individualized radiation therapy that is maximally accurate and precise.

“Gynaecological Malignancies - Updates and Advances” aims to present a review of the significant advances in the understanding and management of gynaecological malignancies. Major areas of importance in this field will be covered, incorporating new knowledge that has arisen due to the advancements in molecular techniques and the ability to correlate these molecular changes with clinical behaviour of gynaecologic tumours. The therapeutic implications of molecular subtyping to match appropriate therapies and the appreciation of the use of up to date radiotherapy techniques will be explored.

Thoroughly updated throughout, this second edition of Monte Carlo Techniques in Radiation Therapy: Applications to Dosimetry, Imaging, and Preclinical Radiotherapy, edited by Joao Seco and Frank Verhaegen, explores the use of Monte Carlo methods for modelling various features of internal and external radiation sources. Monte Carlo methods have been heavily used in the field of radiation therapy in applications such as dosimetry, imaging, radiation chemistry, modelling of small animal irradiation units, etc. The aim of this book is to provide a compendium of the Monte Carlo methods that are commonly used in radiation therapy applications, which will allow students, postdoctoral fellows, and university professors to learn and teach Monte Carlo techniques. This book provides concise but detailed information about many Monte Carlo applications that cannot be found in any other didactic or scientific book. This second edition contains many new chapters on topics such as: Monte Carlo studies of prompt gamma emission Developments in proton imaging Monte Carlo for cone beam CT imaging Monte Carlo modelling
of proton beams for small animal irradiation Monte Carlo studies of microbeam radiation therapy Monte Carlo in micro- and nano-dosimetry GPU-based fast Monte Carlo simulations for radiotherapy This book is primarily aimed at students and scientists wishing to learn and improve their knowledge of Monte Carlo methods in radiation therapy.

Breast Cancer - From Biology to Medicine thoroughly examines breast cancer from basic definitions, to cellular and molecular biology, to diagnosis and treatment. This book also has some additional focus on preclinical and clinical results in diagnosis and treatment of breast cancer. The book begins with introduction on epidemiology and pathophysiology of breast cancer in Section 1. In Section 2, the subsequent chapters introduce molecular and cellular biology of breast cancer with some particular signaling pathways, the gene expression, as well as the gene methylation and genomic imprinting, especially the existence of breast cancer stem cells. In Section 3, some new diagnostic methods and updated therapies from surgery, chemotherapy, hormone therapy, immunotherapy, radiotherapy, and some complementary therapies are discussed. This book provides a succinct yet comprehensive overview of breast cancer for advanced students, graduate students, and researchers as well as those working with breast cancer in a clinical setting.

Therapeutic Applications of Monte Carlo Calculations in Nuclear Medicine examines the applications of Monte Carlo (MC) calculations in therapeutic nuclear medicine, from basic principles to computer implementations of software packages and their applications in radiation dosimetry and treatment planning. With chapters written by recognized author

This book provides a first comprehensive summary of the basic principles, instrumentation, methods, and clinical applications of three-dimensional dosimetry in modern radiation therapy treatment. The presentation reflects the major growth in the field as a result of the widespread use of more sophisticated radiotherapy approaches such as intensity-modulated radiation therapy and proton therapy, which require new 3D dosimetric techniques to determine very accurately the dose distribution. It is intended as an essential guide for those involved in the design and implementation of new treatment technology and its application in advanced radiation therapy, and will enable these readers to select the most suitable equipment and methods for their application. Chapters include numerical data, examples, and case studies.

NCRP Report No. 116 is the latest in the long series of reports on basic radiation protection criteria that began in 1934. It supersedes the predecessor in the series, NCRP Report No. 91, which was published in 1987. The current Report takes advantage of new information, evaluations and thinking that have developed since 1987, particularly the risk estimate formulations set out in NCRP Report No. 115. While the recommendations set out in this Report do not constitute a radical revision of the basic criteria, they do represent a refinement of the system enunciated in Report No. 91. Important changes include the utilization of revised tissue/organ weighting factors and the introduction of radiation weighting factors. Also noteworthy is the introduction of an allowable reference level of intake. Noteworthy too is the recommendation of an age-based lifetime limit for control of occupational exposures and a major simplification of limits aimed at controlling the exposure of the embryo and fetus. This Report, after outlining the goals and philosophy of radiation protection and the basis for exposure limits, goes on to review, in some detail, absorbed dose, equivalent dose, radiation weighting factors, and effective dose. Committed equivalent dose and committed effective dose are also introduced. Risk estimates for radiation exposure are presented and then the dose limits are enunciated. The Report also covers exposure in excess of the limits, limits for unusual occupational situations, guidance for emergency occupational exposure, and remedial action levels for naturally occurring radiation.

Translational research in oncology benefits from an abundance of knowledge resulting from genome-scale studies concerning the molecular pathways involved in tumorigenesis. Translational oncology represents a bridge between basic research and clinical practice in cancer medicine. The vast majority of cancer cases are due to environmental risk factors. Many of these environmental factors are controllable lifestyle choices. Experimental cancer treatments are studied in clinical trials to compare the proposed treatment to the best existing treatment through translational research. The key features of the book include: 1) New screening for the development of radioprotectors: radioprotection and anti-cancer effect of ?-Glucan (Enterococcus faecalis) 2) Translational perspective on hepatocellular carcinoma 3) Brachytherapy for endometrial cancer 4) Discovery of small molecule inhibitors for histone methyltransferases in cancer
This book presents the proceedings of the IUPESM World Biomedical Engineering and Medical Physics, a triannual high-level policy meeting dedicated exclusively to furthering the role of biomedical engineering and medical physics in medicine. The book offers papers about emerging issues related to the development and sustainability of the role and impact of medical physicists and biomedical engineers in medicine and healthcare. It provides a unique and important forum to secure a coordinated, multileveled global response to the need, demand and importance of creating and supporting strong academic and clinical teams of biomedical engineers and medical physicists for the benefit of human health.

To identify effects of chronic internal and external radiation exposure for components of terrestrial ecosystems, a comprehensive study of Scots pine trees in the Chernobyl Exclusion Zone was performed. The experimental plan included over 1,100 young trees (up to 20 years old) selected from areas with varying levels of radioactive contamination. These pine trees were planted after the 1986 Chernobyl Nuclear Power Plant accident mainly to prevent radionuclide resuspension and soil erosion. For each tree, the major morphological parameters and radioactive contamination values were identified. Cytological analyses were performed for selected trees representing all dose rate ranges. A specially developed dosimetric model capable of taking into account radiation from the incorporated radionuclides in the trees was developed for the apical meristem. The calculated dose rates for the trees in the study varied within three orders of magnitude, from close to background values in the control area (about 5 mGy y\(^{-1}\)) to approximately 7 Gy y\(^{-1}\) in the Red Forest area located in the immediate vicinity of the Chernobyl Nuclear Power Plant site. Dose rate/effect relationships for morphological changes and cytogenetic defects were identified and correlations for radiation effects occurring on the morphological and cellular level were established.

Radioembolization is a widely used treatment for non-resectable primary and secondary liver cancer. This handbook addresses the radiation biology, physics, nuclear medicine, and imaging for radioembolization using Yttrium-90 (90Y) microspheres, in addition to discussing aspects related to interventional radiology. The contents reflect on and off-label treatment indications, dose-response relationships, treatment-planning, therapy optimization, radiation safety, imaging follow-up and many other facets of this therapy necessary for both novice and advanced users alike.

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Accuracy requirements in radiation oncology have been defined in multiple publications; however, these have been based on differing radiation technologies. In the meantime, the uncertainties in radiation dosimetry reference standards have been reduced and more detailed patient outcome data are available. No comprehensive literature on accuracy and uncertainties in radiotherapy has been published so far. The IAEA has therefore developed a new international consensus document on accuracy requirements and uncertainties in radiation therapy, to promote safer and more effective patient treatments. This publication addresses accuracy and uncertainty issues related to the vast majority of radiotherapy departments including both external beam radiotherapy and brachytherapy. It covers clinical, radiobiological, dosimetric, technical and physical aspects.

Basic Clinical Radiobiology is a concise but comprehensive textbook setting out the essentials of the science and clinical application of radiobiology for those seeking accreditation in radiation oncology, clinical radiation physics, and radiation technology. Fully revised and updated to keep abreast of current developments in radiation biology and radiation oncology, this fifth edition continues to present in an interesting way the biological basis of radiation therapy, discussing the basic principles and significant developments that underlie the latest attempts to improve the radiotherapeutic management of cancer. This new edition is highly illustrated with attractive 2-colour presentation and now includes new chapters on stem cells, tissue response and the convergence of radiotherapy, radiobiology, and physics. It will be invaluable for FRCR (clinical oncology) and equivalent candidates, SpRs (and equivalent) in
radiation oncology, practicing radiation oncologists and radiotherapists, as well as radiobiologists and radiotherapy physicists.

The move towards individually-optimised treatments, using knowledge of normal tissue and tumour radiosensitivity, proliferation rates, etc, in combination with three-dimensional planning, will need mathematical modelling to achieve its full potential. This modelling process will also be capable of helping develop a rational and cost-effective use of resources. Amongst radiation oncologists and medical physicists there is a need for a greater understanding of the scope, applications and limitations of radiobiological modelling, particularly in complex situations that include multiple treatment variables, the respective influence of which are difficult to separate out by randomised trials without using radiobiologically-based analysis. In future there will be increasing use of modelling in practical situations, including treatment gap corrections, normal tissue tolerance predictions, optimisation of therapy determined by predictive assays, multi-modality schedule design, the simulation of clinical trials, testing contemporaneous medico-legal problems and teaching general principals of radiotherapy.

Over fifty years have passed since the first patient was treated with fast neutrons, but this form of therapy is still a matter of bitter dispute. Neutron generators have been installed in many countries and now patients can be treated with equipment that is technically similar to modern megavoltage x-ray equipment. The Physics and Radiobiology of Fast Neutron Beams presents a full discussion of the physical and radiobiological factors governing the production and use of fast neutron beams for therapy. The book discusses vastly improved neutron generators, advances in the standardization of dosimetric methods, and the specification of radiation quality. In addition, it explores nuclear methods of analysis, particularly neutron activation analysis in vivo. Influencing the place of radiotherapy with neutrons and other heavy particles, the radiobiological factors governing the treatment of cancer with radiation are examined. The author also studies the radiation hazard of neutrons, a matter of importance in the use of neutrons for chemical analysis in vivo. The Physics and Radiobiology of Fast Neutron Beams will be a valuable introduction to the subject for radiotherapists, medical physicists, radiographers, and radiobiologists new to the field. The book is also a useful summary of current knowledge for those already established in the use of fast neutrons for medical purposes.

Purpose: To quantify the effect of a strong static magnetic field (SMF) on DNA damage and electron transport during Iridium-192 irradiation. Methods: A commercial plasmid DNA was loaded into a small well phantom that was 3-D printed with biocompatible tissue equivalent material. The phantom contained two pathways through which a transfer tube was inserted for irradiation with an Ir-192 HDR brachytherapy source. A CT scanner was used to scan the phantom with 1 mm thick slices to construct a treatment plan designed to deliver 50 Gy (±4%) to ten samples each in the presence and absence of a 1.5 Tesla (T) SMF. Agarose gel electrophoresis was used to separate the DNA into bands corresponding to single strand breaks (SSBs) and double strand breaks (DSBs). The intensities of the DNA bands were analyzed, and the relative yields of SSBs and DSBs were computed. Triplicate radiochromic film measurements were performed in two other phantoms and irradiated to 5 Gy in the presence and absence of a 1.5 T magnetic field. The films were scanned, and the 2-D dose distribution in two planes (sagittal and coronal), and in a small region of interest at the center of the films were analyzed. Results: The average yield of irradiated DNA with SSBs in the presence and absence of the SMF was 0.833±0.027 and 0.804±0.014, respectively. The average yield of irradiated DNA with DSBs in the presence and absence of the SMF was 0.062±0.013 and 0.077±0.008, respectively. Statistical analysis comparing the average yields of DNA suggest a statistically significant difference between the yields (p