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MEETING REPORT

Education and Training for Radiation Scientists: Radiation Research Program and American Society of Therapeutic Radiology and Oncology Workshop, Bethesda, Maryland, May 12–14, 2003

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Current and potential shortfalls in the number of radiation scientists stand in sharp contrast to the emerging scientific opportunities and the need for new knowledge to address issues of cancer survivorship and radiological and nuclear terrorism. In response to these challenges, workshops organized by the Radiation Research Program (RRP), National Cancer Institute (NCI) (*Radiat. Res.* 157, 204–223, 2002; *Radiat. Res.* 159, 812–834, 2003), and National Institute of Allergy and Infectious Diseases (NIAID) (*Nature*, 421, 787, 2003) have engaged experts from a range of federal agencies, academia and industry. This workshop, Education and Training for Radiation Scientists, addressed the need to establish a sustainable pool of expertise and talent for a wide range of activities and careers related to radiation biology, oncology and epidemiology. Although fundamental radiation chemistry and physics are also critical to radiation sciences, this workshop did not address workforce needs in these areas. The recommendations include: (1) Establish a National Council of Radiation Sciences to develop a strategy for increasing the number of radiation scientists. The strategy includes NIH training grants, interagency cooperation, interinstitutional collaboration among universities, and active involvement of all stakeholders. (2) Create new and expanded training programs with sustained funding. These may take the form of regional Centers of Excellence for Radiation Sciences. (3) Continue and broaden educational efforts of the American Society for Therapeutic Radiology and Oncology (ASTRO), the American Association for Cancer Research (AACR), the Radiological Society of North America (RSNA), and the Radiation Research Society (RRS). (4) Foster education and training in the radiation sciences for the range of career opportunities including radiation oncology, radiation biology, radiation epidemiology, radiation safety, health/government policy, and industrial research. (5) Educate other scientists and the general public on the quantitative, basic, molecular, translational and applied aspects of radiation sciences.

INTRODUCTION

The capacity of the United States to foster new developments in radiation science, translate research in radiation science to people with cancer, and respond to radiological emergencies and nuclear terrorism is limited by a shortfall

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in the number of appropriately trained personnel (*1*). The discoveries made possible by the tools and techniques of molecular biology are providing new insights into the interactions of radiation with cells and tissues. As these discoveries progress toward clinical application for treatment of cancer and radiation injuries, researchers require an understanding of the concepts, principles and tools of the radiation sciences (*2*). Radiation oncologists must have a fundamental understanding of the effects of ionizing radiation, not only to practice their profession today, but also to evaluate new treatment approaches as they are developed and to incorporate them into their practice.

Advances in radiation oncology are essential to address the needs of cancer survivorship, as emphasized in the NCI Bypass Budget (NCI Plans and Priorities for Cancer Research: http://plan.cancer.gov), and to achieve the NCI challenge goal of eliminating death and suffering due to cancer by 2015. Basic and translational radiation scientists will also be required to serve as teachers and mentors in imparting an integrated knowledge of the field to future researchers and clinicians. The education and training of the next generation of radiation scientists must begin now to ensure that the necessary cadre of experts is available to meet the current and future needs of society.

The Radiation Research Program (RRP), in conjunction with the American Society for Therapeutic Radiology and Oncology (ASTRO), convened a 3-day workshop to assess the needs for radiation scientists, assess the state of education and training in radiation sciences, and recommend a course of action. This workshop built upon recommendations of: (1) previous RRP workshops on treatment of radiation-induced normal tissue injury (*3*) and moderate-dose (1–10 Gy) radiation effects (*4*–*6*), (2) an NCI Late Effects of Cancer Treatment Workshop to update criteria for normal tissue injury (*7*), (3) the ''NCI Listens'' session at the annual ASTRO meeting (October 6–10, 2002, New Orleans, LA), (4) a Department of Homeland Security report on preparations for nuclear/radiological terrorism (http://www.va.gov/emshg/docs/Radiologic_Medical_Countermeasures_051403.pdf), and (5) the response of the NIH under the direction of NIAID (*8*) to develop an overall plan to address the issues resulting from radiological and biological terrorism. In addition, a panel of Canadian radiation biologists and radiation oncologists has recently addressed concerns about the need for education and training for translational research in radiation oncology (submitted to *Radiother. Oncol.*; http://www.caro-acro.ca).

Workshop Organization

The priorities of the workshop were education and training of radiation scientists:

1. To address the current and projected shortfalls of researchers in the field.
2. To respond to radiological terrorism.
3. To address the need for educators for the next generation of radiation researchers and other radiation experts.
4. To instruct radiation oncology residents and other medical personnel who use ionizing radiation.

The content of radiation biology courses for radiation oncology residents is being addressed primarily by ASTRO and Radiation Research Society (RRS) working groups (*9*–*11*), by the Society of Chairpersons of Academic Radiation Oncology Programs (SCAROP), and by the American Board of Radiology (ABR) and was mentioned only briefly at this workshop.

This workshop report should be of interest to practicing radiobiologists (researchers and teachers), students considering a field of specialization for graduate education, radiation oncologists, university administrators, and government professionals involved in the health, regulatory or security aspects of radiation.

The definition of a radiobiologist or radiation scientist used *for the purposes of this workshop* was anyone using ionizing radiation as a perturbing agent and studying the effects of radiation on living systems or their components. This included such areas as the effects of radiation on cellular or tissue components, the effects of radiation on cell cycle and radiation-induced DNA damage/repair, perturbation of signaling systems by radiation, effects on irradiated cells in culture and their progeny (including bystander effects), effects of radiation on tissues, animals and humans, effects of radiation in combination with other agents, genetic effects of radiation, radiation-induced genomic instability, and radiation epidemiology and risk assessment.

The following related areas, while also part of the larger field of radiation sciences, and also important, were not addressed at this workshop: radiation chemistry in inorganic systems, pure radiation physics and physical dosimetry, and engineering and technology development.

The recommendations were proposed in the following general time frame: immediate: within 1 year; intermediate: 1 to 5 years; long-term: >5 years.

Appendix I lists the workshop participants and Appendix II the agenda. This report is largely a consensus document, although it must be emphasized that for almost every issue addressed, there remains a healthy diversity of opinions.

General Considerations

Many conference participants felt that the terms ''classical radiobiology'' and ''modern radiobiology'' unnecessarily divide the field rather than underscore its breadth. The wealth of information from basic radiation biology models and the discipline's rigorous quantitative approach to data remain extremely useful in assessing the importance of mechanism-based molecular, cellular and tissue research and also in the design of clinical treatments including fractionation and combined-modality therapy.

One of the strengths of the field is that it is interdisciplinary and multidisciplinary. Radiation scientists must have a thorough grounding in both the basic sciences and radiation effects in their chosen area of specialization.

TABLE 1
Radiation Science Education: The Trainees

Researchers studying radiation effects
Faculty to educate future researchers
Residents in radiation oncology
Medical students
Physicians
Radiotherapists, radiation oncology nurses
Allied health care professionals: nurses, EMTs, others
Undergraduate students
Emergency responders: military, police, fire
Federal government employees: grant review and administration
Regulatory affairs officials: community, state, national level
Media representatives
Secondary school teachers and students
Community groups, public at large

While the advances and tools in molecular biology, for example, are essential for determining mechanisms of cell and tissue response to radiation, the concepts and tools of radiation biology must also be employed in determining the relevance of the findings for radiation oncology, carcinogenesis, mutagenesis and other radiation effects. Quantification has always been an important part of the radiation sciences and must be included in molecular studies. A new generation of researchers employing radiation in their research will need to understand such concepts and techniques as dose–response relationships and log cell killing, the generation and interpretation of survival curves, mutagenesis, carcinogenesis, effects of whole-body irradiation and radiotherapy, the terminology of modification of radiation response and its quantification, the time course and multiple modes of radiation-induced cell death, the effect of the schedule or protraction of exposure on the response of tumors or normal tissues, differences in radiation response among organisms and among different tissues and organs, and differences in effects produced by external exposure and internally deposited isotopes and by different types and energies of radiation.

New approaches are needed to attract, recruit and retain top-quality scientists to address the broad spectrum of issues in the radiation sciences. Members of the radiation research community must collaborate and cooperate in shaping the future of the discipline. The diversity of interests and expertise, the breadth of career opportunities, and the ability to apply research to human needs are among the greatest strengths of this field.

Challenging scientific questions are essential for attracting bright young scientists to the field. Addressing these questions will require interdisciplinary and multidisciplinary research teams working at universities, government agencies and industries. The societal need accompanied by funding for specific areas of immediate concern, such as nuclear terrorism and cancer survivorship, will attract people to this field. Outstanding leadership and superb mentoring and support of young scientists and faculty are crucial to sustained excellence.

While individual scientists are responsible for being thoroughly familiar with the basic concepts, literature, techniques and tools that are relevant to their research, the scientific community also contributes to the scientific endeavor and ensures its integrity. This community includes all those who disseminate and use this information, such as mentors, colleagues, editors and reviewers.

Education and Training: Current Status

The spectrum of people who require or could benefit from understanding the effects of ionizing radiation on living systems is shown in Table 1.

Because of the diversity of the groups, the education and training needs are diverse as well. The interdisciplinary and multidisciplinary nature of the field presents challenges for developing and implementing educational programs. As mentioned above, radiation researchers must be rigorously educated in both basic and radiation sciences. Radiation scientists must take the lead in meeting these challenges. In addition to traditional college courses, single lectures, one-on-one training and workshops must be developed (*1*, *9*).

1. Graduate programs

In April and May 2003, we surveyed the institutions listed under ''Graduate Education'' in the website of the Radiation Research Society (http://www.radres.org). We identified 36 institutions in the U.S. and Canada at which a predoctoral student could undertake a thesis project studying radiation effects (see Table 2). Most of the graduate programs in which those students enroll are part of larger interdisciplinary programs with such names as ''Cancer Biology'', ''Molecular Biology'' or ''Biophysics.'' Only nine institutions have active graduate programs in which the word ''radiation'' (or a synonym) is part of the name of the program. A similar survey undertaken in 1978 by the RRS

TABLE 2
Survey of Predoctoral Programs

	U.S.	Canada
Number of institutions with graduate programs offering thesis project in radiation biology	33	3
Number of above programs with students currently enrolled	25	3
Number of programs with ''radiation'' or a synonym in the name of the program	9	0
Number of Ph.D. degrees granted with a thesis project in radiation biology in last 3 years	65	4
Number of students with a thesis project in radiation biology currently enrolled in all programs	141	22

reported similar findings (*12*). Conversely, there are students and faculty in radiation departments working on projects that have their roots in radiation studies, such as hypoxia, but that do not involve radiation.

2. Courses in radiation biology

The coursework requirements vary considerably among institutions, in number and in classroom hours as well as in students' areas of specialization (e.g. photodynamic therapy, stress responses). The most common courses in radiation biology are those required in residency programs in radiation oncology. While these are generally open to all interested parties, students would become more aware of their availability if the courses were formalized, offered for credit, and listed in university course catalogs. Predoctoral students and postdoctoral fellows working on projects involving radiation should be required to take them. This would encourage students' commitment to regular class attendance and study. It is important that supervisors convey to students the high priority of taking such courses, with or without credit.

One approach is to present basic concepts in refresher courses in conjunction with scientific meetings. A radiation science refresher course entitled ''A Primer on Resident Teaching: Everything You (N)ever Wanted to Know About Survival Curves'' was presented by Elaine Zeman at the annual RRS meeting in Reno, NV (April 22–23, 2003). Of the attendees who responded to a survey at the conclusion of the course, the following is noteworthy:

1. Approximately half the respondents anticipated teaching radiation and cancer biology to radiation oncology residents.
2. Approximately half had never taken a formal course in the classical aspects of radiation biology.
3. Approximately two-thirds had never taken a formal course in the clinical aspects of radiation biology as applied to radiation oncology.

These results reflect an interest in the principles of radiation biology among junior scientists. Expanding these opportunities at radiation meetings and at other national and international scientific meetings could be undertaken quickly and should be given high priority.

Radiation Science: Career Opportunities

Radiobiology jobs can sometimes be difficult to identify in job placement advertisements, because they are categorized under broad categories such as ''cancer'' or ''biophysics'' rather than under ''radiobiology.'' While most of the discussion at the workshop centered around researchers affiliated with radiation oncology departments and their role in teaching radiation biology to residents, the potential market for individuals with training in radiation sciences extends far beyond clinical radiation departments to include industrial concerns, state and federal agencies and international organizations, media outlets, financial institutions, and legal offices (see Table 3).

TABLE 3
Radiation Science: Who Provides Jobs?

Academic institutions
Colleges
Universities
Academic medical centers
Regional cancer treatment centers
National laboratories and other research institutions
Industry
Biotechnology
Pharmaceuticals
Food management (e.g. environmental impact of pest, bacterial irradiation)
Government agencies
Regulatory agencies at local, state, federal, international levels (e.g. NRC)
Public health agencies (e.g. DHHS/NIH)
Other governmental and quasi-governmental organizations (e.g. NASA, NSF, NAS)
Waste management
Legal affairs specialists
Financial institutions (technology assessment)
Media outlets (science, medicine, technology reporting)

The managed-care revolution has had two major detrimental effects on translational research, including that in radiation oncology (see 1994 report from the National Academy of Sciences, available at http://www.nap.edu/catalog/9911.html). It has put pressure on clinicians to maximize patient loads, leaving little or no time for research by clinicians and residents. In addition, there has been a decline in the availability of funds generated from clinical revenue that formerly supplemented the support of research laboratories affiliated with radiation oncology departments. These problems have had an impact on other fields of medical research and teaching as well (*13*). The complexity of current medical research provides opportunities for scientists to work in interdisciplinary teams with physicians (*14*) so that physician-scientists are critical to the success in translating basic science to human application.

Of particular importance are radiation scientists who can respond to the needs arising from the current threat of radiological terrorism, including laboratories devoted to radiation monitoring, dose assessment, biomarkers, biodosimetry and emergency response; research for improving security and protective and therapeutic measures; planning for emergency response and improving responses; security and risk analyses; educational programs serving a wide range of audiences; and effective communication to the public.

RECOMMENDATIONS FROM THE BREAKOUT GROUPS

A. The Discipline

The breadth and scope of radiation sciences are expanding while the number of personnel with broad expertise in this area is decreasing, especially as senior investigators reach retirement age. The scope includes oncology, diagnostic imaging, terrorism, environment, power generation, emergency medicine, molecular and cellular biology, biodosimetry, epidemiology, safety/health physics, biomathematical modeling, space science and others. To meet these anticipated workforce demands, education and training programs should be expanded.

Recommendations

1. Immediate: Create a National Council for Radiation Sciences (NCRS), with members representing RRS, ASTRO, Radiological Society of North America (RSNA), Free Radical Society (FRS), American Association of Physicists in Medicine (AAPM), Health Physics Society (HPS), Environmental Mutagen Society (EMS), American College of Radiology (ACR), and others.
   a. Analyze the current portfolio of researchers and research topics of institutions that would be expected to be involved in radiation research including cancer centers, national laboratories, universities, nuclear industries, government agencies, etc.
   b. Enhance integration among radiation science disciplines, societies and professional organizations.
   c. Collaborate with the federal agencies on the projects above.
2. Intermediate
   a. Develop National Training Centers for Emergency Response.
   b. Develop programs for educating the public on radiation effects and radiation risks.
   c. Develop Special Programs for Understanding Radiation Sciences (SPURS): multidisciplinary, collaborative training programs specializing in such areas as terrorism, space, environment, health care, etc.
3. Long-term
   a. Coordinate efforts among the subdisciplines of the radiation sciences to strengthen and expand the scope of this field.
   b. Be attentive to and meet changing national needs in radiation sciences.

B. Research

One of the strengths of radiobiology research is the quantitative approach that has been applied to the studies of the interaction of radiation with biological systems. Increasingly, as with other scientific and translational research fields, phenomenological and descriptive research has given way to more mechanistic approaches leading to an understanding of molecular and cellular processes and pathways. As molecularly targeted agents are developed, however, quantification will be necessary to evaluate and select the most promising for clinical trials.

Since radiobiological research programs in laboratories or sections within clinical radiation oncology departments may be somewhat isolated from basic science groups, radiation scientists must make the effort to interact and collaborate with them to foster understanding by the basic scientists of radiation principles and techniques and implications of research that involves radiation. Radiation scientists will benefit as well from these interactions.

None of the NCI-designated Comprehensive Cancer Centers is led by a radiation oncologist or radiobiologist, and few Cancer Centers have radiation scientists in leadership positions. Changing this at even a few Cancer Centers would expand the understanding of the field.

The establishment of regional and multi-institutional Centers of Excellence for Radiation Sciences could create a critical mass of expertise and professional networking.

Recommendations

1. Immediate to intermediate
   a. Enhance and promote leadership by radiation scientists in Cancer Centers and Cancer Biology groups.
   b. Encourage the inclusion and/or development of a strong radiation research component in NCI-designated Comprehensive Cancer Centers. This may require new planning grants or supplements to existing P50 Cancer Center grants. It should be emphasized that molecularly targeted therapies (e.g. cytostatic compounds) are unlikely to be effective on their own, and that radiation therapy and/or cytotoxic chemotherapy will be needed for the most effective treatment of cancer patients.
   c. Support new infrastructure for research in radiation sciences (i.e. laboratory space and equipment).
   d. Give high priority to radiation research applicable to dealing with radiological and nuclear terrorism, including technology, biomarkers, biodosimetry, etc., as well as normal tissue injury. (1) The U.S. Government should provide the appropriate level of support for radiological and nuclear terrorism research. (2) Investigators should work with industry to establish a collaborative research infrastructure.
2. Immediate to long-term: Promote research in the following areas:
   a. Normal tissue responses to radiation, which are relevant to the acute and long-term effects in radiation oncology and radiological terrorism: requires tissue biologists, physiologists, radiation oncologists.
   b. Regeneration, repopulation and repair of hematopoietic stem cells both *in situ* and in bone marrow transplantation for nuclear accidents/terrorism: requires cell biologists, physicians (hematologists and oncologists), growth factor experts.
   c. Effects of radiation on growth, development and cognition: requires developmental biologists, neurobiologists, psychologists, animal model experts.
   d. Radiation carcinogenesis: requires geneticists, DNA repair experts, epidemiologists, toxicologists.

e. Biodosimetry and biomarkers: requires toxicologists, molecular biologists, epidemiologists.
f. Genetic susceptibility: requires geneticists, experts in single nucleotide polymorphisms (SNPs), genomics, proteomics, etc.
g. Rapid response networking for radiological/nuclear terrorism response programs: requires national databases for sharing information, to allow rapid response to national emergencies.

C. Education and Training: Goals and Implementation

Recommendations:

1. Establish a network of Centers of Excellence in Radiation Sciences to provide funding, coursework and instruction in radiation sciences, and websites targeting potential trainees and students. The Centers may be regional multi-institutional programs. Centers may also establish specific areas of emphasis and cover the full spectrum of research and education. The network could facilitate training by allowing students to work in more than one Center to enhance the breadth of their education.
2. Identify and recruit students from a variety of backgrounds and educational programs, including:
   a. Predoctoral and postdoctoral students.
   b. Medical students.
   c. Undergraduates.
   d. Clinicians managing late effects of therapy, radiological accidents and terrorism victims.
   e. Allied health care professionals (e.g., nurses, emergency medical technicians), elementary and secondary school teachers, local citizens involved in homeland security activities.
3. Radiation biology courses for residents, predoctoral and postdoctoral students, medical students and undergraduates should be offered as formal courses for credit and appear in university course listings. Additional courses for both university and non-university trainees should include day-long courses/tutorials before or after the annual meetings of professional societies (e.g. RRS, ASTRO, AACR, RSNA), as well as specialty workshops and meetings (e.g. DNA repair, molecular oncology, biodefense, etc.).
4. Publicize the availability of funds for education and training from the National Institutes of Health (NIH), including Ruth L. Kirschstein National Research Service Award (NRSA) Institutional Training Grants (T32, for predoctoral and postdoctoral candidates), National Cancer Institute Cancer Education and Career Development Program awards (R25T, for predoctoral and postdoctoral candidates), Ruth L. Kirschstein NRSA For Individual Postdoctoral Fellows (F32), Ruth L. Kirschstein National Research Service Awards For Minority Students (F31), and Ruth L. Kirschstein NRSA Predoctoral Fellowship Awards For Students With Disabilities (F31).
5. Expand the continuing education sessions offered by such organizations as ASTRO, RRS, RSNA and AACR. Provide education necessary for licensing examinations. Provide continuing medical education (CME) opportunities for groups that would benefit from an increased knowledge of radiation biology and nuclear terrorism response, including allied health care professionals.

Projected Timelines:

1. Immediate:
   a. Review available grant mechanisms and develop plans to submit applications.
   b. Enhance and broaden the current training programs.
2. Intermediate: Establish 1–2 new accredited education programs within universities.
3. Long-term: Award doctoral degrees, fund new postdoctoral fellows.

D. Perception/advocacy

Perception: We have not adequately educated the public or the scientific community about the biological effects of radiation.

Recommendations:

1. Immediate:
   a. Write and publish short review papers on topics in radiation sciences for highly visible journals, such as *Science, Nature, New England Journal of Medicine,* or *Lancet.*
   b. Write letters to journals to call attention to and correct inaccuracies and misconceptions in published articles involving the use of radiation.
   c. Develop ‘‘Ask the Expert’’ and FAQ sections for websites such as those of RRS and ASTRO.
   d. Be certain that RRS, ASTRO and other radiation science societies have effective intersociety web links.
   e. Call attention to articles of wide interest using mechanisms such as EurekAlert! (http://www.eurekalert.org/).
   f. Nominate appropriate reviewers for articles related to the radiation sciences to the editors of major scientific journals.

Advocacy: Effectiveness of the field as a whole would be enhanced by better coordination of the efforts of the radiation societies noted above in a National Council for Radiation Sciences.

Recommendations:

1. Immediate:
   a. Recommend that officers of radiation societies establish regular formal contact to better coordinate advocacy of common interests.
   b. Take advantage of the opportunities to contribute to the needs of the Department of Homeland Security. This will increase the visibility of the radiation sciences.

   c. Contact and work with state and local governments, radiation offices and public safety officials.
   d. Develop a website as a source of information on radiation effects for the general public.
   e. Continue high-level coordination among Federal agencies engaged in radiation research and biodefense [e.g. the Radiobiology Bioterrorism Research and Training working group (RABRAT), comprised of members from RRP and DCEG of NCI, DOE, AFRRI, EPA and NASA].

CONCLUSIONS

The following next steps are recommended, including potential participants and lead groups:

1. Establish a National Council of Radiation Sciences (NCRS) with the appropriate stakeholders that addresses the issues of NIH training grants, interagency cooperation, interinstitutional collaboration among universities, and other relevant activities.
   a. Members of this workshop, working with RRS, RSNA and ASTRO: Take the lead.
   b. Federal agencies: Coordinate and communicate to address issues of radiological/nuclear terrorism and radiation education and training.
2. Develop new training programs and expand existing ones with sustained funding. These may take the form of Centers of Excellence.
   a. Individual institutions and collaborating institutions: Review the educational grant mechanisms of the NIH and NCI and consider applying for R25T and T32 grants. Consider expanding currently funded training programs and developing new consortia for training.
   b. AFRRI, in collaboration with other agencies and institutions: Accelerate plans to develop an educational program in radiation sciences within the Uniformed Services University for Health Sciences in collaboration with neighboring regional programs.
3. Continue and broaden the education programs of ASTRO, RSNA and RRS.
   a. More radiation biology courses should be offered for formal credit.
   b. Education and training in radiation sciences should be offered at a range of venues.
4. Develop education and training opportunities for careers in oncology, epidemiology, radiation safety, health/government policy and industrial research.
5. Educate other scientists and the general public on the important principles and concepts in radiation sciences, including the quantitative, basic, molecular, translational and applied radiation sciences.
   a. Explain the importance of this knowledge to basic science, cancer survivorship, and radiological and nuclear terrorism.
   b. Individuals and societies engaged in radiation research and related service functions: Be active in addressing these issues.

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APPENDIX I
Attendees

Name	Degree	Primary affiliation
Universities, Cancer Centers and Societies		
Barcellos-Hoff, Mary Helen	Ph.D.	Lawrence Berkeley National Laboratory
Bedford, Joel	Ph.D.	Colorado State University; also a member of BRER
Bristow, Robert	M.D., Ph.D.	Princess Margaret Hospital, University of Toronto
Daly, Nancy	M.P.H.	ASTRO
Dewey, William	Ph.D.	University of California, San Francisco
Dynlacht, Joseph	Ph.D.	Indiana University
Ethier, Steve	Ph.D.	University of Michigan
Freeman, Michael	Ph.D.	Vanderbilt University
Fuks, Zvi	M.D.	Memorial Sloan-Kettering Cancer Center
Goldberg, Zelanna	M.D.	University of California, Davis
Hill, Richard	Ph.D.	Ontario Cancer Institute, University of Toronto
Joiner, Michael	Ph.D.	Wayne State University
Liu, Fei-Fei	M.D.	Princess Margaret Hospital, University of Toronto
McBride, William	Ph.D.	University of California, Los Angeles
McKenna, W. Gillies	M.D., Ph.D.	University of Pennsylvania
Mendonca, Marc	Ph.D.	Indiana University
Powell, Simon	M.D., Ph.D.	Massachusetts General Hospital
Robbins, Michael	Ph.D.	Wake Forest University School of Medicine
Rockwell, Sara	Ph.D.	Yale University
Schiff, Peter	M.D., Ph.D.	Columbia Presbyterian Hospital
Shaw, Edward	M.D.	Wake Forest University School of Medicine
Siemann, Dietmar	Ph.D.	University of Florida
Travis, Elizabeth	Ph.D.	University of Texas M. D. Anderson Hospital
Ullrich, Robert	Ph.D.	Colorado State University
Woloschak, Gayle	Ph.D.	Northwestern University
Zeman, Elaine	Ph.D.	University of North Carolina
NIH and other federal agencies		
Alexander, George	M.D.	Office of Technology Transfer, NCI, and White House Office
Bouville, Andre	Ph.D.	Radiation Epidemiology Branch, NCI
Coleman, Norman	M.D.	ROSP, RRP, NCI
Deye, James	Ph.D.	RRP, NCI
Gorelic, Lester	Ph.D.	Cancer Training Branch, NCI
Inskip, Peter	Ph.D.	DCEG, NCI
Mahoney, Francis J.	Ph.D.	RRP, NCI
Metting, Noelle	Ph.D.	DOE
Okano, Paul	Ph.D.	DCB, NCI
Pellmar, Terry	Ph.D.	DOD/AFRRI
Puskin, Jerome	Ph.D.	EPA
Simon, Steven	Ph.D.	Radiation Epidemiology Branch, NCI
Stone, Helen	Ph.D.	RRP, NCI
Strudler, Paul	Ph.D.	Center for Scientific Review, NIH
Tenforde, Thomas	Ph.D.	NCRP
Wachholz, Bruce	Ph.D.	DCB, NCI
Wallner, Paul	D.O.	RRP, NCI
Wong, Rosemary	Ph.D.	RRP, NCI
Young investigators		
Costes, Sylvain	Ph.D.	NCI-Frederick
Greco, Olga	Ph.D.	Wayne State University
Pervan, Milena	Ph.D.	University of California, Los Angeles
Vujascovic, Zeljko	M.D., Ph.D.	Duke University
Yun, Zhong	Ph.D.	Stanford University

APPENDIX II
Workshop Agenda

Monday evening, May 12, 2003		
7:30–7:45 p.m.	Welcome and Introduction	C. Norman Coleman and Helen Stone
7:45–8:15	The Spectrum of Researchers in radiobiology	Michael Robbins and Gillies McKenna
8:15–8:35	Report on ''Current Status and Future Prospects for Translational Radiobiology as Relates to Radiation Oncology in Canada''	Robert Bristow, for CARO Task Force in Translational Radiobiology
8:35–8:55	Radiobiology Education in Europe	Michael Joiner
8:55–9:15	Report on Survey on Teaching Radiation Oncology Residents	Elaine Zeman
Tuesday, May 13		
8:30–10:00	What general research areas will be (or should be) most active in radiation research in the next few years, and what radiobiology concepts are essential background for carrying out this research. What are the frontiers of radiation biology research?	Richard Hill, Fei-Fei Liu, Simon Powell
10:00–10:30	Where are the programs for training radiobiologists?	Joseph Dynlacht
10:45–11:05	What concepts in radiobiology do radiation oncologists—and their instructors—need to know? Curriculum Development for Radiation Oncology Residents	William McBride
11:05–11:20	The radiation oncology residency programs in the U.S.	Peter Schiff, Paul Wallner
11:20–12:00	Where are the jobs for radiobiologists, and what is the projected need?	Paul Wallner, Sara Rockwell, Zvi Fuks
1:00–1:45	Recruiting talented students to the field	Mary Helen Barcellos-Hoff
1:45–2:00	Support during predoctoral training	Lester Gorelic
2:00–3:00	When money and time are at a premium, how can we equip researchers and teachers with the background they need in radiobiology?	Dietmar Siemann, Edward Shaw
3:15–3:30	Educating the outsiders: researchers who use radiation in their research	Elizabeth Travis, Joseph Dynlacht
3:30–5:15	Discussion: Preliminary Recommendations	William McBride, Joel Bedford, Robert Bristow
Wednesday, May 14		
8:30–12:00	Development of Recommendations and Action Plan Working groups and all participants Working groups: The Discipline (McBride), Research (Bristow), Training (Zeman), Perception/advocacy (Bedford)	William McBride, Joel Bedford, Robert Bristow, Elaine Zeman

APPENDIX III
Glossary

AAPM	American Association of Physicists in Medicine
ACR	American College of Radiology
AFRRI	Armed Forces Radiobiology Research Institute, DOD
ASTRO	American Society for Therapeutic Radiology and Oncology
BRER	Board on Radiation Effects Research, National Academy of Sciences
CARO-ACRO	Canadian Association of Radiation Oncologists-Association Canadienne des Radio-Oncologues
DCB	Division of Cancer Biology, NCI, NIH, DHHS
DCEG	Division of Cancer Epidemiology and Genetics, NCI, NIH, DHHS
DOD	Department of Defense
DOE	Department of Energy
EMS	Environmental Mutagen Society
EPA	Environmental Protection Agency
HPS	Health Physics Society
NASA	National Aeronautics and Space Agency
NCI	National Cancer Institute, NIH
NIAID	National Institute of Arthritis and Infectious Diseases, NIH
NIH	National Institutes of Health, Department of Health and Human Services
RRP	Radiation Research Program, Division of Cancer Treatment and Diagnosis, National Cancer Institute, NIH, DHHS
RRS	Radiation Research Society
RSNA	Radiological Society of North America