COLUMBIA UNIVERSITY MEDICAL CENTER

CENTER FOR RADIOLOGICAL RESEARCH
630 WEST 168TH STREET
NEW YORK, NY 10032

David J Brenner, PhD, DSc
Higgins Professor of Radiation Biophysics
Director, Columbia University Center for Radiological Research
Phone: (212) 305-5660
FAX: (212) 305-3229
djb3@columbia.edu

Committee on Oversight and Government Reform
Subcommittee on National Security, Homeland Defense & Foreign Operations
"TSA Oversight Part 1: Whole Body Imaging"
March 16, 2011, 9:30 am
2154 Rayburn House Office Building

Thank you, Mr. Chairman, for the opportunity to testify before this subcommittee on the potential health significance of the x-ray exposures associated with AIT (Advanced Imaging Technology) whole-body scanners currently being deployed at US airports.

My name is Dr. David J. Brenner, and I am the Higgins Professor of Radiation Biophysics at Columbia University Medical Center in New York. I am the Director of the Columbia University Center for Radiological Research, which is considered the oldest and largest radiological research center worldwide, being founded in 1915 by a student of Marie Curie. The Columbia University Center for Radiological Research focuses on understanding the biological effects of ionizing radiation, both at high doses for cancer radiotherapy, and also at low radiation doses in the context of environmental exposures, occupational exposures, and x-ray imaging. I myself have been in the field of radiation risk estimation for about 30 years, and have published more than 250 peer-reviewed scientific papers on radiation risk estimation, as well as two books. In the present context I have just had published a peer-reviewed paper in the well known journal "Radiology" entitled "*Are X-Ray Backscatter Scanners Safe for Airport Passenger Screening? For Most Individuals, Probably Yes, but a Billion Scans per Year Raises Long-Term Public Health Concerns*".

Without doubt, improved scanning for explosives of individuals boarding airline flights is both desirable and necessary. Currently there are several possible technology options in this regard, and I will focus here on the radiation safety of the most commonly deployed AIT (Advanced Imaging Technology), namely whole-body x-ray backscatter scanners. I will first summarize my three main conclusions, and then provide more in depth discussion:

Summary

1. Using the most credible dose and risk estimates that we have, one can say that the individual radiation-induced cancer risks associated with a few whole-body x-ray backscatter scans are likely to be extremely small. Our best estimate is that the chance of any given individual developing cancer as a result of the x-ray exposure from a few scans is around 1 in 10 million. Thus it is reasonable to say that, for an average individual, the scanners are "safe".
   - *However, individual lifetime cancer risks will be somewhat higher for children, radiosensitive individuals and, particularly, for aircrew and for very frequent fliers.*

2. As well as individual risk, however, from a public-health / policy perspective it is important also to take into account the population risk. This relates to the number of cancers induced in the whole population as a result of scanner use. In that x-ray backscatter scans have become a primary screening measure, very large numbers of people will likely be exposed to very small radiation-associated cancer risks from the associated radiation exposure.
   - *Given the very large numbers of scans involved, potentially up to one billion each year in the US, there is a significant likelihood that, amongst the scanned population, there will be some cancers produced by the associated radiation exposure. A best estimate is around 100 cancers per year, though this number is quite uncertain.*

3. Given that it is unlikely that the alternative airport whole body-scanning technology (millimeter wave) will be associated with population cancer risks, from a public health perspective, they may be a preferable advanced whole-body imaging technology.

Background

Whole-body x-ray backscatter scanners have been deployed at US airports since 2007, though in fairly small numbers and to screen limited numbers of passengers. Indeed back in 2003 the National Council for Radiological Protection (NCRP) published a report on their use and safety, of which I was one of the five co-authors. In early 2010, however, in response to the Dec 25 2009 "underwear bomber" incident, the TSA (Transportation Security Administration) shifted the goalposts dramatically with regard to the use of whole-body AIT scanners. As reported by the Government Accountability Office "*In response to the Dec 25 2009 terrorist attack, the TSA has revised its procurement and deployment strategy for AIT, increasing the number of AITs it plans to procure and deploy. In contrast with its prior strategy, the agency now plans …. to use them as a primary screening measure where feasible, rather than solely as a secondary screening measure*".

In other words, instead of using whole-body AIT scanners for a small number of selected passengers, the goal now is to use them for all US airline passengers. The number of commercial passenger emplanements per year is currently about 700 million and is predicted by the FDA to reach one billion by about 2023. While the number of times passengers pass through security will be slightly less than the number of passenger emplanements, it is clear that there is the potential for as many as one billion whole-body scans per year in US airports.

In fact there are two quite different AIT whole-body scanner technologies currently being deployed at airports. One uses x-ray backscatter technology, scanning the whole body with a narrow beam of x-rays both from the front and from the back. The second whole-body screening technology illuminates the subject with low power millimeter-waves.

In contrast to x rays, millimeter-waves are non ionizing[1]. Our primary concern here will be in regard to the x-ray scanners, which represent the majority of deployed whole-body AIT scanners in US airports. In that the TSA has purchased and is deploying both x-ray and millimeter wave systems, it is reasonable to assume that both have comparable characteristics in terms of sensitivity, specificity and logistics.

What Do We Mean by "Safe"?

This testimony addresses the issue of whether whole-body x-ray backscatter systems are "safe", so it is important to be clear about what "safe" can mean in this context.

The most direct interpretation of "safe" refers to the exposed individual. One may ask what is the best estimate of the lifetime cancer risk incurred by an individual receiving one or more of these scans? But risks can and should also be viewed from the perspective of the entire exposed population. The estimated population risk (sometimes called the societal risk) in this case relates to the number of cancers expected in the exposed population as a result of the proposed practice; this population outcome depends, of course, both on the individual risk *and on the number of people exposed to that risk.*

To illustrate this distinction between individual and population risk, consider a hypothetical activity producing an extremely small individual cancer risk of (say) 1 in ten million. An individual cancer risk of 1 in 10 million means that if 10 million people were exposed to this activity, on average one cancer would be induced. So if, for example, only 100 people were exposed to this activity, it would be extremely unlikely that any of the 100 exposed individuals would actually develop cancer due to the activity in question. Now consider one billion (one hundred million) people exposed to that same very small cancer risk of 1 in ten million: in this case it would be very likely that some of the exposed population would develop cancer due to the activity in question – a significant population risk.

The major national and international organizations that recommend radiation standards (International Commission on Radiological Protection [ICRP] and the US National Council for Radiological Protection [NCRP]) have both stated that, as well as individual risk, population risk is an appropriate measure for assessing the acceptability of a large-scale activity that might be associated with small individual radiation risks. Thus, population risk is described by the ICRP as "one input to …. a broad judgment of what is reasonable", and by the NCRP as "one of the means for assessing the acceptability of a facility or practice".

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[1] *Ionizing radiations, such as x rays (but not millimeter waves), are those that have enough energy to knock electrons out of atoms, and can thus damage and break biological molecules such as DNA.*

Population risks are also routinely considered in other fields where policy choices involve large populations potentially exposed to small individual risks. For example the World Health Organization has developed approaches to estimate current and future population risks from diverse risk factors such as air pollution and climate change. Other areas where population risks have been used to inform policy decisions include civil aviation, flood control, second-hand smoke, and vaccination policy. For example, both the small individual risk of meningitis from pediatric measles vaccination and the population risks, are taken into account in formulating measles vaccination policies.

Estimating Individual Risks Associated with X-Ray Backscatter Scanners

The radiation doses required to produce images of the appropriate resolution and quality are extremely low, around 1 micro-Sievert (μSv). We do not know with any certainty the magnitude of the individual cancer risks associated with such low doses. Epidemiological studies of radiation risks at these doses are exceedingly difficult, essentially because there are so many cancers in any studied population that are from other (non radiation) causes.

However, we can make a best estimate of the individual radiation risk associated with an x-ray backscatter scan. Following the guidance of all the primary radiation regulatory and advisory agencies (ICRP, NCRP, UNSCEAR, BEIR), we use standard cancer mortality risk formulae that relate dose with cancer risk. This results in a best estimate for the lifetime cancer mortality risk of about 1 chance in 10 million for two x-ray backscatter screening scans.

This best-estimate risk estimate is quite uncertain, in large part because it is based on extrapolation of radiation risks estimated at much higher doses. Indeed, some have argued that the individual risk at very low doses is still lower; by contrast others have argued that recently studied phenomena such as tissue/organ microenvironment effects, bystander effects, and “sneaking through” immune surveillance suggest that low-dose radiation risks could be higher.

In terms of the significance of very small individual risks, the NCRP has defined a “Negligible Individual Risk Level” (NIRL) as “the level of annual excess risk of fatal health effects attributable to radiation, below which efforts to reduce radiation exposure to the individual are unwarranted”. Not quite the same as “safe”, but a reasonable practical proxy. The NCRP has suggested an NIRL value of 1 in ten million, which is similar to the estimated fatal cancer risk from two scans. It is not unreasonable, therefore, to describe x-ray backscatter scans as “safe”, in terms of the individual risk associated with a small number of such scans.

One could perhaps debate whether this “safe” descriptor should apply to the scan of a child, where the cancer risks are probably 5 to 10 higher than for exposure in middle age, or for radiosensitive individuals (including the embryo and fetus), or for air-flight personnel, or for very frequent fliers. For example US domestic aircrew passes through security in the range of 240 to 380 times per year. Likewise a very high-level frequent flier averages more than 200 flights per year from x-ray backscatter scans. In these cases the corresponding best estimate risk of a radiation-induced fatal cancer is around 1 chance in 100,000.

Estimating Population Risks Associated with X-Ray Backscatter Scanners

Given our estimates of individual risks, and the number of scans projected to take place each year in the US, how many cancers do we expect to be caused by the radiation from airport x-ray whole body scanners?

In the present context, if one billion (1,000 million) x-ray backscatter scans were performed each year in the US, and the average individual cancer risk per scan is 1 in 10 million (see above), one might eventually anticipate an expected 100 cancers each year resulting from this activity. Of course, as is now discussed, hidden behind this back of the envelope calculation are a number of issues and uncertainties, some practical and some conceptual.

The first uncertainty in the population risk estimate relates to the uncertainty associated with the individual risk, as discussed above. It is perfectly possible that the individual risk could actually be significantly lower (or indeed zero), but it is also quite possible that the individual risk could actually be significantly higher. One can make plausible mechanistically-based arguments either way here – and indeed people have, but it is certainly reasonable to base the best-estimate population risk on the best-estimate individual risk.

There have also been suggestions that it is not reasonable to estimate population outcome by multiplying small individual risks by the number of people exposed to those risks. It is hard to see the logic behind this suggestion, nor is there empirical evidence to support it, and indeed it has been widely disputed. To take a simple analogy: If millions of people buy lottery tickets, the chance that any particular person will win is extremely small. But it does not follow that there will be a population outcome where *nobody* wins. On the contrary, some people will win – it is just that we cannot predict beforehand who they will be. It is essentially the same situation when hundreds of millions of people are exposed to an extremely small radiation risk.

ALARA: As Low As Reasonably Achievable

The ALARA (As Low As Reasonably Achievable) principle, universally accepted in the field of radiation protection, requires making every reasonable effort to minimize ionizing radiation exposures as far below dose limits as is practical, consistent with practically achieving the desired goal. In the context of x-ray backscatter passenger screening there are two relevant consequences of ALARA:

1. Comparisons with other risks are not necessarily relevant. The fact that flying involves other radiation exposures, or other different risks, is not relevant to the ALARA requirement to minimize the ionization radiation exposure associated with practical passenger screening. In another context, for example, one would not ignore the radiation exposures associated with CT scans simply because domestic radon exposure involves larger effective doses.
2. If there is a non ionizing-radiation alternative that can reasonably achieve the same screening goal, then, consistent with the ALARA principle, it should be used in preference to an x-ray related technology. As far as is known, millimeter wave whole-body scanner technology fulfills this requirement. In terms of specificity, sensitivity, cost, and speed, the millimeter

wave technology is generally comparable to that of the x-ray backscatter technology. Of course one cannot rule out the possibility of adverse health effects associated with low-power millimeter wave radiation but, in contrast to the situation for x rays, there are no established mechanisms associated with millimeter-wave induced carcinogenesis, and extensive studies have not revealed evidence of potential deleterious effects.

Conclusions: Are X-Ray Backscatter Scanners Safe for Passenger Screening?

In conclusion, individual cancer risks associated with the radiation exposure from a few whole-body x-ray backscatter scans are undoubtedly very small. There are indeed uncertainties regarding the doses (the most recent estimates of the doses required to produce images of the relevant resolution and quality, thought still extremely low, are an order of magnitude higher than earlier estimates, and there are even more uncertainties regarding the cancer risks, if any, associated with these very low radiation doses. Using the most credible dose and risk estimates that we have, one can say that the individual radiation-induced cancer risks associated with a few whole-body x-ray backscatter scans are likely to be of the same order as the NCRP Negligible Individual Risk Level (NIRL) of 1 in 10 million, and can therefore be reasonably described as safe. Best estimate lifetime cancer risks will be somewhat higher for children, radiosensitive individuals and, particularly, for aircrew and for very frequent fliers. Again it is important to emphasize the associated uncertainties in these individual risk estimates, which could result in the actual risks being either less than or greater than the best estimates discussed here.

As well as individual risk, however, from a public-health perspective it is important also to take into account the population risk, described by the NCRP as “one of the means for assessing the acceptability of a facility or practice” and by the ICRP as “one input to …. a broad judgment of what is reasonable”. In that x-ray backscatter scans have become a primary screening measure, very large numbers of people will likely be exposed to very small radiation-associated cancer risks from the associated radiation exposure. Given the very large numbers of scans involved, potentially up to one billion each year in the US, there is a significant likelihood that, amongst the scanned population, there will be some cancers induced by the associated radiation exposure. A best estimate is around 100 cancers per year, though this number is quite uncertain.

If there were no feasible alternatives to x-ray backscatter scanners, it could certainly be argued that such population risks would be more than balanced by the associated benefits of reducing the risk of a terrorist event. However, millimeter wave scanners are a feasible and practical whole-body scanning technology which does not involve ionizing radiation, and for which there is currently essentially no mechanistic or experimental evidence of biological risks. Whatever the actual radiation risks associated with x-ray backscatter machines, the ALARA principle clearly implies that a comparable technology which does not involve x rays is a preferable alternative.

Thank you for your attention.

Committee on Oversight and Government Reform
Witness Disclosure Requirement – "Truth in Testimony"
Required by House Rule XI, Clause 2(g)(5)

Name: David J. Brenner, Ph.D., D.Sc.

1. Please list any federal grants or contracts (including subgrants or subcontracts) you have received since October 1, 2008. Include the source and amount of each grant or contract.

PLEASE SEE ATTACHED LIST

2. Please list any entity you are testifying on behalf of and briefly describe your relationship with these entities.

NO

3. Please list any federal grants or contracts (including subgrants or subcontracts) received since October 1, 2008, by the entity(ies) you listed above. Include the source and amount of each grant or contract.

N/A

I certify that the above information is true and correct.
Signature: David Brenner

Date: Mar 11 2011

List of Federal Grants/Contracts Received Since October 1, 2008 by
David J. Brenner, Ph.D., D.Sc.
Higgins Professor of Radiation Biophysics &
Director, Center for Radiological Research
Columbia University Medical Center

Award Number	Funding Source/Sponsor	Project Title	Project Period	Direct Cost	Indirect Cost	Total Cost
P41 EB002033	National Institute of Biomedical Imaging & Bioengineering (NIBIB)	Radiological Research Accelerator Facility (RARAF)	9/1/04-8/31/14	$ 6,426,454	$ 3,695,777	$ 10,122,231
U19 AI067773	National Institute of Allergy and Infectious Diseases (NIAID)	Center for High-Throughput Minimally-invasive Radiation Biodosimetry	8/1/05-7/31/15	$ 31,188,977	$ 9,482,289	$ 40,671,266
3 U19 AI067773-05S1 (ARRA, Supplement of U19 grant above)	National Institute of Allergy and Infectious Diseases (NIAID)	Center for High-Throughput Minimally-invasive Radiation Biodosimetry	9/22/09-8/31/11	$ 249,659	$ 150,340	$ 399,999
NGC 8140000583 (subcontract)	Northrop Grumman Corporation/ Biomedical Advanced Research and Development Authority (BARDA)	High-Throughput Biodosimetry After Radiological and Nuclear Events	12/09/09-08/23/13	$ 3,037,228	$ 1,614,776	$ 4,652,004
R21ES019494	National Institute of Environmental Health Sciences (NIEHS)	High-Throughput Technology for Assessing Global DSB Repair Capacity	2/1/11-1/31/13	$ 275,000	$ 167,750	$ 442,750
HDTRA1-07-1-0025	Defense Threat Reduction Agency (DTRA)	Metabolomics-Based Rapid Biodosimetry for Partial-Body Exposures	2/1/07-7/31/11	$ 512,705	$ 252,117	$ 764,822
4R44RR023753	Energetiq Inc - subcontract (SBIR)	Development of an X-ray microbeam facility based on a plasma X-ray source	06/18/07-12/17/10	$ 253,838	$ 106,701	$ 360,539
DE-FG02-03ER6363	US Department of Energy (DOE)	A Validated High-LET Radiation Specific Biomarker in the Mayak Worker Cohort	12/29/05-11/30/09	$ 361,057	$ 220,245	$ 581,302
DOE CU52222902 (conference grant)	US Department of Energy (DOE)	7th International Workshop on Microbeam Probes of Cellular Radiation Response	12/01/05-11/30/08	$ 29,530	$ -	$ 29,530

Curriculum Vitae

DAVID JONATHAN BRENNER, Ph.D., D.Sc.

Homepage: www.columbia.edu/~djb3 *Email:* djb3@columbia.edu

Date of Birth:	9 June 1953	
Place of Birth:	Liverpool, England	
Nationality:	British	
Status:	Permanent Resident of USA	
Education:	1963-1970	Merchant Taylors' School, Liverpool, England.
	1971-1974	Oxford University, St. Edmund Hall, reading Physics and Philosophy. Awarded Carter Physics Prize, 1974. Degrees obtained: B.A., M.A.
	1975-1976	Medical College of St. Bartholomew's Hospital, University of London. Degree obtained: M.Sc. in Radiation Physics (Distinction)
	1976-1979	University of Surrey, Physics Department Degree obtained: Ph.D. Thesis Title: *Pion Interactions with Light Nuclei and Applications to Radiotherapy*

APPOINTMENTS

2008-	Higgins Professor of Radiation Biophysics and Director, Center for Radiological Research, Columbia University Medical Center, Professor of Environmental Health Sciences.
1994-	Professor of Radiation Oncology and Public Health, and Director, Radiological Research Accelerator Facility, Center for Radiological Research, Columbia University Medical Center.
1993-94	Tenured Associate Professor of Radiation Oncology and Public Health, Center for Radiological Research, College of Physicians & Surgeons of Columbia University.
1992-93	Associate Professor of Radiation Oncology (Tenure), Center for Radiological Research, College of Physicians & Surgeons of Columbia University.
1986-92	Assistant Professor of Radiation Oncology, College of Physicians & Surgeons of Columbia University.
1983-86	Associate Research Scientist, Radiological Research Laboratory, College of Physicians & Surgeons of Columbia University.
1981-83	Staff Member, Los Alamos National Laboratory.
1979-81	Postdoctoral Fellow, Los Alamos Scientific Laboratory.

AWARDS

Douglas Lea Lecturer, UK Radiation Oncology Congress, 2009

Selby Lecturer, Memorial Sloan Kettering Cancer Center, 2009

G. William Morgan Lecturer, Health Physics Society, 2008

2nd Annual Jean Roy Memorial Lecturer, Canadian Association of Radiation Oncology, 2002

University of California, Berkeley, Miller Professor, 2002

Honorary Degree (Doctor of Science), Oxford University, 1996.

Winner, 1992 National Council on Radiation Protection and Measurements, Robert D. Moseley Award for Radiation Protection in Medicine.

Winner, 1991 Radiation Research Society Annual Research Award.

Oxford University Carter Physics Prize, 1974

P.I. of NIH Grant "*High Throughput Technology for Assessing Global DSB Repair Capacity*" 2011-13

P.I. of NIH Grant "*Center for Minimally-Invasive High-Throughput Radiation Biodosimetry*" 2005-15

P.I. of NIH grant "*Radiological Research Accelerator Facility*" 1996-2013

P.I. of NIH grant "*Cancer Risks Attributable to Radiation from Pediatric CT*" 2002-2007

P.I. of DOE grant "*A Validated High-LET-Radiation Specific Biomarker in the Mayak Worker Cohort"* 2001-2009

P.I. of DOE grant "*The Bystander Effect: Modeling, experiments, and More Modeling"* 2001-2007

P.I. of DOE grant: "*mFISH Measurements of Chromosomal Aberrations in Individuals Exposed In Utero to Low Doses of Gamma Rays" 2002-2005*

P.I. of Society of Pediatric Radiology grant: "*Credible risk estimates for pediatric CT examinations"* 2001-2002

P.I. of NIH grant "*Clinical mammographic imaging and cancer risks*" 1998-2001

P.I. of DOE grant "*Genetic, cytogenetic and oncogenic effects of low doses of low-energy (< 50 keV) x rays, measured at the National Synchrotron Light Source*" 1998-2002

P.I. of NIH grant "*Chromosomal Fingerprints of Prior Exposure to Neutrons and Alpha Particles*", 1996-2000

P.I. of NASA grant "*Dose Rate Effects with Fast Protons*", 1992-1993.

P.I. of ACS Grant "*High vs Low Dose Rate for Cervical Carcinoma*", 1991-1994.

P.I. of NIH grant "*Radon, Bronchial Morphometry and Occupational Health*", 1991-1994

P.I. of NIH Grant "*Early Effects of Radiation-Induced Radicals*", 1985-1989

MEMBERSHIPS and COMMITTEES

Director, Radiological Research Accelerator Facility, Columbia University

Member, National Council on Radiation Protection and Measurements (NCRP)

Member, National Academy of Sciences BEIR VI Committee, 1994-98

Member, National Council on Radiation Protection Committee 1-6, on Linearity of Dose Response, 1995-2000

Chairperson, Columbia University Radiation Safety Committees, 1992-

Editorial Board, Radiation and Environmental Biophysics, 2002-

Member EPA Science Advisory Sub-Committee on Radon Research, 1993-96.

Associate Editor, International Journal of Radiation Biology, 1991-1996

Member, Columbia University Senate, 1985-1987.

Physics Councilor, Radiation Research Society Executive Council, 1993-1996.

TEACHING

Teacher, Columbia University School of Public Health *Core Course in Environmental Sciences.*

Teacher of *Radiobiology for Radiation Oncology/Radiology Residents* (Columbia-Presbyterian Medical Center).

Teacher of Columbia University School of Public Health course P6320, *Radon, Risk and Remedy*

Teacher of undergraduate course *Radiation and Life*. Columbia University, Dept. of Biology,

PATENTS GRANTED

US Patent 5,818,054: *Substance Detection with Monoenergetic Neutrons* (with G. Randers-Pehrson)

BOOKS

"*Radon, Risk and Remedy*", D. J. Brenner (W. H. Freeman, New York, 1989).

"*Making the Radiotherapy Decision*", D. J. Brenner and E. J. Hall (Lowell House, 1996)

PEER-REVIEWED PAPERS

1.* Brenner, D. J. and Smith, F. A. *Dose and LET distributions due to neutrons and photons emitted from stopped negative pions*. Phys. Med. Biol., *22,* 451-465 (1977).

2.* Brenner, D. J. and Reading, D. H. *A method for measuring neutron spectra in a stopping pion field*, Nucl. Instr. Meth., *153,* 137-144 (1978).

3. Jackson, D. F. and Brenner, D. J. *Nuclear interactions for medical purposes*, Prog. Part. Nucl. Phys., *5*, 143-204 (1981).

4.* Brenner, D. J. *Monte Carlo self-shielding corrections for use with neutron spectrum unfolding codes*, Nucl. Sci. Eng., *78*, 175-177 (1981).

5. Zaider, M., Dicello, J. F., Brenner, D. J., Takai, M., Raju, M. R. and Howard, J. *Microdosimetry of range-modulated beams of heavy ions I. Determination of the yield of projectile fragments from microdosimetric spectra for neon beams*. Radiat. Res., *87,* 511-520 (1981).

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10. Atari, N., Malik, S. R., Brenner, D. J., Hilko, R. and Bradbury, J. N. *A lyoluminescent tissue-equivalent dosemeter for pion therapy beams.* Phys. Med. Biol., *28*, 493-502 (1983).

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12. Goodhead, D. T. and Brenner, D. J. *Estimation of a single physical property of low LET radiations which correlates with their biological effect*. Phys. Med. Biol., *28*, 485-492 (1983).

13. Subramanian, T. S., Romero, J. L., Brady, F. P., Watson, J. W., Fitzgerald, D. H., Garrett, R., Needham, G. A., Ullman, J. L., Zanelli, C. I., Brenner, D. J. and Prael, R. E. D*ouble differential inclusive hydrogen and helium spectra from neutron induced reactions on carbon at 27.4, 39.7, and 60.7 MeV.* Phys. Rev., *C28*, 521-528 (1983).

14.* Brenner, D. J. and Zaider, M. *The application of track calculations to radiobiology.-II. Calculations of microdosimetric quantities*. Radiat. Res., *98*, 14-25 (1984).

15. Zaider, M. and Brenner, D. J. *The application of track calculations to radiobiology.--III. Analysis of the molecular beam experiment results*. Radiat. Res., *100*, 213-221 (1984).

16. Zaider, M. and Brenner, D. J. *On the stochastic treatment of fast chemical reactions.* Radiat. Res., *100*, 245-256 (1984).

17.* Brenner, D. J. and Prael, R. E. *The C(n,n')3α cross-Section up to 60 MeV.* Nucl. Sci. Eng., *88*, 97-101 (1984).

18.* Brenner, D. J. *Neutron kerma values above 15 MeV calculated with a nuclear model applicable to light nuclei.* Phys. Med. Biol., *29*, 437-441 (1984).

19.* Brenner, D. J. and Zaider, M. *A computationally convenient parameterisation of experimental angular distributions of low energy electrons elastically scattered off water vapour.* Phys. Med. Biol., *29*, 443-447 (1984).

20. Zaider, M. and Brenner, D. J. *Comments on `V79 Survival following simultaneous or sequential irradiation by 15-MeV neutrons and Co photons` by Higgins et al. [Radiat. Res. 95, 45-56(1983)]*. Radiat. Res., *99,* 438-441 (1984).

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23. Zaider, M. and Brenner, D. J. *On the microdosimetric definition of quality factors.* Radiat. Res., *103*, 302-316 (1985).

24.* Brenner, D. J. and Zaider, M. *Stochastic and deterministic treatments of the time decay of species created by heavy-charged particle interactions.* Radiat. Prot. Dosimetry, *13*, 127-131 (1985)

25. Hoshi, M., Goodhead, D. T., Brenner, D. J., Bance, D. A., Chmielewski, J. J., Paciotti, M. A. and Bradbury, J. N. *Dosimetry comparison and characterisation of an Al K ultrasoft X-ray beam from an MRC cold-cathode source.* Phys. Med. Biol., *30*, 1029-1041 (1985).

26. Zaider, M. and Brenner, D. J. *Evaluation of a Specific Quality Function for mutation induction in human fibroblasts.* Rad. Prot. Dosim., *15*, 79-82 (1986).

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28.* Brenner, D. J., Zaider, M., Coyne, J. J., Menzel, H. G. and Prael, R. E. *The evaluation of non-elastic neutron cross-sections on carbon above 14 MeV.* Nucl. Sci. Eng. *95*, 311-315 (1987)

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30.* Brenner, D. J., Geard, C. R., Zaider, M. and Georgsson, M. A. *Cell survival and plating efficiency*. Radiat. Res. *111*, 572-576 (1987)

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