I R P S BULLETIN

Newsletter of the International Radiation Physics Society

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From the Editor:

As readers will see from this issue there was *some* response to my plea for contributions. The response, however, could hardly be regarded as overwhelming. As I have said in this column on several occasions: we must learn to communicate better.

Which leads me to my topic for this issue. I was recently at the opening of an exhibition at an art gallery when the current French nuclear tests at Muraroa Atoll was being discussed, very heatedly, by a group of people. What caught my attention was not the low standard and ill-informed nature of the debate but the low esteem in which scientists, and physicists in particular, were held by all participating in the discussion.

It seems that we are all evil geniuses (like Dr Frankenstein), or morally deficient nerds, or criminally negligent fools whose committal to a sheltered workshop should be immediate. Those of us who are in the field of "Radiation Physics "are accorded even more violent descriptions.

Where do these notions come from? There is no doubt that scientists have always received bad press for writers. Mary Shelley and Jules Verne did us no favours. Nor did the animators of children's cartoons like "Felix the Cat", nor the writers of the "Dr Who" television series, nor the film " Dr Strangelove". The perceptions of the world at large are fashioned, almost from the cradle, to regard scientists as less than capable, deficient of morality, and lacking the finer feelings.

The nett result is that, whilst the general public readily accepts the benefits which flow on from the work of scientists, they are totally ignorant of the work which has gone into the creation of the benefits.

What can be done? It is too late to change the images formed by the writers of fiction and the creators of television or film extravaganzas. What we must work towards is more interaction by scientists with the community in which they live. It is important that ordinary people, your friends and neighbours, members of your church, businessmen, know what you do, and gain an appreciation for the value of your work. Scientists are very bad at talking about their work with laymen, whether through diffidence or an inability to reduce what they know to simple terms.

Until we can learn to ***communicat**e* scientists will never fill their proper place in society. Many important initiatives will be overlooked, misunderstood, and to the detriment of society until we learn to speak simply to others about our work.

So please: ***communicate with others: communicate with me.***

Make the IRPS Bulletin a sounding board for your ideas!!

Dudley Creagh

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PRESIDENT'S COLUMN

John Hubbell

1995 and Some Anniversary Reflections:

We tend to quantize our lives into multiples of the decades of years through which each of us has inhabited this planet. I have arrived at four of these "punctuation marks" in the flow of my life (and some in yours), here in 1995. I hope my IRPS friends and fellow members will indulge me by letting me use this column to recount a few reflections and reminiscences evoked by this conjunction of anniversaries. Of course, there is an additional important anniversary in 1995 which predates my life, also to be mentioned.

10th Anniversary of the IRPS: The IRPS was founded in 1985 in Ferrara, Italy at the 3rd International Symposium on Radiation Physics (ISRP-3) organized by **Ernesto Casnati** and his colleagues **Claudio Baraldi**, **Agostino Tartari and others**. The concept of forming such a Society had grown out of conversations with **Anu Ghose**, **Suprakash Roy**, **D.V. Gopinath** and others at ISRP-1 in Calcutta in 1974. More detailed plans were developed at ISRP-2 in Penang in 1982, and there a pro tem Committee to establish the Society was formed, consisting of **A.M. Ghose** (India), Chair, **J.H. Hubbell** (U.S.), Secretary, **Daphne Jackson** (U.K.), **D.B. Isabelle** (France), **A. Ljubicic** (Yugoslavia [Croatia]), **M.A. Gomaa** (Egypt), **P.K. Iyengar** (India), and **I.B. Whittingham** (Australia). Then in 1985 at ISRP-3 in Ferrara, at a nice Italian restaurant, glasses were raised in a toast as this core group declared the IRPS to exist, with Officers informally agreed upon, with their acceptances, to serve until an election would be held prior to the next Symposium three years hence. These first Officers, who served 1985-1988 were: **P.K. Iyengar** (India), President, **R.H. Pratt** (U.S.), Secretary, and **D.B. Isabelle** (France), Treasurer, plus Regional Vice Presidents **G.F. Knoll** (U.S.), The Americas, **M.A. Gomaa** (Egypt), Africa and Middle East, **A. Ljubicic** (Yugoslavia [Croatia]), East Europe and the USSR, **D.F. Jackson** (U.K.), Western Europe, and **A.M. Ghose** (India), Asia and the Pacific. The first IRPS Executive Council also included Members **D. Berenyi** (Hungary), **E. Casnati** (Italy), **D.V. Gopinath** (India), **J.H. Hubbell** (U.S.), **T. Nakamura** (Japan) and **I.B. Whittingham** (Australia). Two of these stalwarts are now "gone but not forgotten": **Daphne Jackson** (1991) and **Didier Isabelle** (1995). The little silver handbell, which **Ernesto Casnati** presented to the IRPS at the close of ISRP-3 for opening and closing our Symposia, is now ten years old. We hope it will enjoy many more decades of service.

40th Wedding Anniversary: On June 11, 1955 I became married to **Jean Norford**, whom many of you have met since she accompanied me to ISRP-1 (1974) in Calcutta, to ISRP-3 (1985) in Ferrara, to ISRP-5 (1991) in Dubrovnik, to ISRP-6 (1994) in Rabat, and according to our present plans she will be with me at ISRP-7 (1997) in Jaipur to share the howdah with me on the elephant ride up the hill to the Amber Fort (among other IRPS Presidential obligations!). She has been a behind-the-scenes tireless and creative volunteer for the IRPS, including typing up an initial draft of the IRPS Constitution. At the above-mentioned Ferrara dinner at which we raised our glasses in a toast to declare the establishment of the IRPS, she was invited as a special guest, although her glass (and mine) contained water, not wine, as you know we are teetotalers (no alcohol). We have three children (in Washington, California and Saudi Arabia) and six grandchildren, and I would not trade the past 40 years with Jean for any other scenario.

50th Anniversary of the End of World War II: May 1945 and August 1945 marked the endings of World War II hostilities in Europe and in the Pacific, respectively. I had been drafted for military service immediately upon graduation in 1943 at age 18 from my High School in Manistee, Michigan. At that rash age I thought it would be neat to be an Air Force fighter pilot, being infused with the Air Force song "We live in fame, go down in flame, ..." and general U.S. spirit of that era. However, my poor eyesight disqualified me from this more-glamorous military occupation, and I was relegated to the U.S. Army Infantry "the queen of battle." In my Infantry basic training in Camp Hood, Texas in the summer of 1943 my eyeglasses met with a breakage accident just before my rifle range shooting "for record." As a result (I think) of my very poor score shooting the rifle, I was sent to Europe, for a time under General Patton's command, as the gunner in a machine-gun squad in an infantry front-line company, with my job mainly to maintain a fusillade of bullets (every fifth one a tracer, to see where they were going, and unfortunately also disclosing where they were coming from) over the heads of the advancing riflemen of my company, to keep the enemies' heads down and reduce their defensive fire. Fortunately, I have no recollection of actually seeing someone, either friend or foe, fall from my fire, although there were of course bodies from either side in evidence when we overran the enemy position in each case. To make a long story short, after May 1945, my unit geared up to head for the Pacific and the invasion of the Japanese mainland, where I was to continue my above hazardous, gruesome and unpleasantly confrontational occupation. Hence with the events of August 1945 and the abrupt final close of World War II, terrible as the unspeakable horrors of the bombs were to the people directly affected, I consider myself as one of the many, U.S. and Japanese alike, who were "saved by the bomb." For example, at the "50 Years with Nuclear Fission" Symposium at NIST in 1989, **Paul Kuroda** mentioned that, without the finality of the bombs, he would have been on the beach with his bamboo spear, defending to the death his homeland against the invasion (and I would have been on the other end of that spear, neither of us by choice).

As a more-pleasant and recent follow-up to the above 1945 events, in April 1995 I visited the University of Michigan Phoenix Memorial Laboratory, in Ann Arbor. Directed by IRPS member **Ron Fleming** (formerly at NIST), the Laboratory was conceived and created in the early 1950's as a memorial to the 585 members of the University community and alumni who had died in World War II. The Laboratory is directed totally to peaceful uses of atomic energy, accepting no Defense Department nor classified work. With its main tool an "open pool" 2- megawatt reactor operating since 1957, its projects have included work in medicine, biology, botany, geology, physics, social sciences, law, engineering, and in many other disciplines. The happy occasion for this Ann Arbor visit was to accept the 1995 Outstanding Alumnus Award from the University of Michigan Nuclear Engineering Department, an honor I understand was kindly instigated by **Glenn Knoll**, former Department Chair and a former IRPS Vice President (the Americas).

70th Birthday: I was born in Ann Arbor, Michigan April 9, 1925, son of Civil Engineer Howard Hubbell, also a Michigan alumnus, and of my mother Mildred who received her schoolteacher training in nearby Ypsilanti, walking distance from Ann Arbor for my father during their courting days. In 1925 Charles Lindberg had yet to make his historic solo flight across the Atlantic (1927). These past 70 years have seen major changes (advances?) in our technology, but unfortunately a lot of our human nature seems to be locked back in the stone age, and doesn't mix well with our 1995 high population densities and access to weapons of mass destruction, both nuclear and conventional. Perhaps the IRPS has some small role, as the "global radiation physics family," in defusing some of the tensions which now point us toward further conflagrations, the next having the potential to wipe the human species totally from the face of this incredibly precious blue planet. I would enjoy sticking around to see what mischief (as well as nice things) humanity will get into over the next 70 years, or next 700 years, etc., but I will be content with another decade or two, if such be given to me.

100th Anniversary of Röntgen's Discovery of X Rays: As ably reported by **Leif Gerward** (IRPS Executive Councillor) and **Asger Lindegaard-Andersen** in their excellent article "Centenary of Röntgen's Discovery of the X-Ray" in the September/December i994 issue of the IRPS Bulletin, November 8, 1895 was the day Professor **Wilhelm Conrad Röntgen** made his amazing discovery of the amazing x rays, in the physics laboratory of the University of Würzburg in Bavaria, Germany. This discovery represents the epitome of "radiation physics" and is still our prime example of immediate global human-benefit myriad applications, from radiation physics. **Leif** is exploiting this connection to promote the IRPS by creating and distributing an IRPS poster to the organizers of the many conferences and symposia honoring Röntgen in 1995. This excellent IRPS poster describes all our Symposia from Calcutta to Rabat (and mentions Jaipur) and the purposes and benefits of IRPS membership. If you would like to receive one or more of these colorful and well-designed posters for posting in your own laboratory, please request from:

Prof. Dr. Leif Gerward
Physics Department, Building 307
Technical University of Denmark
DK-2800 Lyngby, Denmark

From the 10th Anniversary of the IRPS (1985) back to the 100th Anniversary of x rays (1895), 1995 marks and evokes remembrances spanning a decade of decades.

REPORTS FROM VICE PRESIDENTS AND COUNCILLORS

From the Vice President for South and Central America : Anselmo Paschoa

The First Workshop Brazil-Germany on the Applications of Surface Sciences took place in Mangaratiba, Hotel Portobello, April 3–7, 1995. The Workshop was jointly financed by Brazilian (CNPq and FINEP) and German (DFG and DAAD) agencies. The total attendance was 96, from which 17 were German participants. Twenty invited talks and 54 posters were presented throughout the Workshop period.

The 46th Annual Meeting of the Brazilian Society for Advancement of Science (SBPC) will be held in São Luiz, Maranhão, Brazil, from 9 to 14 July, 1995. Further information can be obtained from

SBPC – Rua Maria Antônia, 294, 4° andar
São Paulo, SP 01222–010
Phone : +55 11 259 2766
Fax : +55 11 606 1002
Email : sbpc@fox.cce.usp.br .

There will be the 7th Brazilian Workshop on Semiconductor Physics (BWSP–7) in Rio de Janeiro, July 16–21, 1995. For further information contact Patricia Lustosa de Souza

Fax : +55 21 239 7425
Email: semic95@cetuc.puc.rio.br .

From Councillor Takashi Nakamura (Japan)

Monoenergetic and quasi-monoenergetic neutron reference fields have been developed at four accelerator facilities in Japan, as a collaboration between my laboratory, Cyclotron and Radioisotope Center (CYRIC), Tohoku University, Dr. Baba's group of Department of Nuclear Engineering (FNL), Tohoku University, Dr. Shibata's group of Institute for Nuclear Study (INS), University of Tokyo, Dr. Uwamino's group of Institute of Physical and Chemical Research (RIKEN), Dr. Tanaka's Group of Japan Atomic Energy Research Institute (JAERI) and Dr. Shin's group of Department of Nuclear Engineering, Kyoto University.

1) *Monoenergetic neutron field in the energy range from 8 keV to 15 MeV*
   These neutrons are produced by Sc(p,n), Li(p,n), T(p,n), D(d,n) and T(d,n) reactions using the Dynamitron accelerator at FNL.

2) *Quasi-monoenergetic neutron field having 22 and 33 MeV energies*
   These neutrons are produced by Li(p,n) reaction using AVF cyclotron at CYRIC.

3) *Quasi-monoenergetic neutron field in the energy range from 40 to 90 MeV*
   These neutrons are produced by Li(p,n) reaction using AVF cyclotron at TIARA, Takasaki Research Establishment of JAERI.

4) *Quasi-monoenergetic neutron field in the energy range from 80 to 210 MeV.*
   These neutrons are produced by Li(p,n) reaction using separate sector cyclotron at RIKEN.

Using these neutron fields, the following experiments are proceeding:

1) response functions and detection efficiencies of various neutron detectors

2) neutron activation and spallation cross sections

3) neutron-induced charged particle production cross sections

4) neutron penetration through shielding materials

5) neutron capture and scattering cross sections

Our group has also started to do experiment on secondary neutron production by heavy ions at RIKEN and also at Heavy Ion Medical Accelerator Facility of National Institute of Radiological Sciences.

The Committee of Radiation Behavior in Japan Atomic Energy Society plans to invite two foreign researchers, one from Taiwan and one from Korea, to discuss with the international communicative and collaborative works, in this fiscal year, as the first step. Our committee wants to have a good contact with the organizations of radiation field in the neighbouring countries.

ELECTIONS IN 1997

According to the IRPS Constitution, elections of Officers of the Society will take place once every three years. The terms of office for each of the eight Executive Councillors correspond to six years, the terms being so arranged that the terms of half of the councillors expire each three years.

A Nominations/Elections Committee has been designated in preparation for the upcoming 1997 election, the result of which will be announced at the ISRP–7 in Jaipur in late February of 1997. The members of the committee are L. Gerward (Denmark, Chairman), M. Monnin (France), T. Nakamura (Japan), S.C. Roy (India) and F. Rustichelli (Italy).

The Officers of the Society, including the President, the Secretary, the Treasurer and the Vice Presidents, were all elected at ISRP–6 in Rabat, Morocco in July 1994. Thus, new elections should take place in 1997.

Three of the present Executive Councillors, viz. D.A. Bradley, D.C. Creagh and A.M. Ghose, were elected in 1991 NS RHUA Hcw rwema unril 1997. Five Councillors, viz. L. Gerward, M. Monnin, T. Nakamura, S.C. Roy and F. Rustichelli, were elected in 1994. However, one of those seems to represent filling a vacancy, since the Constitution mandates an equal number of Councillors in the two cohorts. If so, one of the five has a three year term. Probably, it has not been specified who, and if so, the Council should be asked to make a decision, perhaps by lot. This should be worked out at the forthcoming Council meeting in Warwick, UK, in November this year.

We do hope, of course, that many of the present Officers and Executive Councillors will be willing to continue to serve the Society in their present capacities. However, the IRPS members should think of possible candidates for the 1997 election. In particular, the need for female representation has been noted and, I believe, is agreed. Since Daphne Jackson's death, we have been an all–maile Council.

In conclusion, we need to identify suitable candidates who are willing to become 9nvolved. If you have any comments or suggestions, please contact the nearest member of the Nominations/Elections Committee.

PAPERS

University of Michigan M.Eng. Radiological Health Engineering: Success during First Year!

Kim Kearfott, Sc.D., C.H.P.

Professor, Dept. Nuclear Engineering
Program Advisor, Radiological Health Engineering
Director of Faculty Development
College of Engineering
University of Michigan
Ann Arbor, MI 48109-2104 USA

Substantial interest was shown in the new Master of Engineering program in Radiological Health Engineering (M.Eng.RHE) at the University of Michigan during its first year of offering, 1994-1995. This new degreeis focused upon engineering solutions to problems in radiation protection,whether these relate to the medical, industrial, or power industries. A total of 14 enrollees, of which 11 were U.S. Citizens or Permanent Residents, arrived for the first offering of the program in Fall 1994. This first-ever class boasted three Department of Energy fellowships (one Applied Health Physics and two Civilian Radioactive Waste Management), one American Nuclear Society Scholarship, and three Health Physics Society Scholarship awards.

In addition to completing the required courses in Radiological Health Engineering Fundamentals, Radiation Biology, and Nuclear Measurements (taught by Prof. Glenn Knoll), popular courses taken by the M.Eng.RHE students included the Physics of Radiology and Nuclear Medicine, a new graduate course in Medical Radiological Health (taught by Prof. Kim Kearfott), and Radiation Shielding. In addition, students in the program enjoyed courses on Radiological Monitoring, Radiation Dosimetry, Applied Radiation Control, and Internal Radiation Dosimetry taught by UM School of Public Health faculty. Courses in bioengineering, environmental engineering, electrical engineering, and industrial engineering rounded out the programs of study of the 1994-95 class.

Although many students took heavy course loads and had varied backgrounds, the average GPA of the students in the program was approximately an A-/B+, with all entering students performing satisfactorily. Of the 14 students who began the program, 12 will have graduated within 12 months of entry (the predicted degree completion time) and the remaining 2 students are expected to graduate at the end of the Fall 1995 semester. Of the 14 students in the 1994-1995 class, six have applied to continue study towards the doctoral degree, one has obtained a position at Batelle Pacific Northwest, and two have accepted positions at the Environmental Protection Agency in New York. Others are currently seeking employment while completing their degree requirements.

For additional information and application forms for the program (which is still accepting applications for the 1995-96 year and already planning its 1996-97 class) contact Ms. Diana Corey at

Phone : +1 (313) 764-4260
e-mail : dhcorey@engin.umich.edu

or write to

Radiological Health Engineering Program
Dept. of Nuclear Engineering
University of Michigan
Ann Arbor MI 48109-2104 USA

Other inquiries concerning the program may be directed to Prof. Kim Kearfott at the above address, or

Phone : +1 (313) 763-9117
Fax : +1 (313) 763-4540
e-mail : kearfott@engin.umich.edu.

What is new in Monte Carlo ?

H. Rief and P.K. Sarkar†*

**Joint Research Centre of the European Union, Ispra-Establishment*

†Visiting Scientist at the Joint Research Centre of the European Union, Ispra-Establishment. Permanent Address: H.P. Unit (VECC)
Bhabha Atomic Research Centre
1/AF Bidhan Nagar, Calcutta 700064, India.

The simulation of complex physical processes on a computer is a well known technique of modern analysis. If the models are of stochastic nature, as for example the random walk of particles, we talk about Monte Carlo techniques. It is conceptually easy to understand how a random walk problem of this kind has to be modelled. It sounds, however, awkward that there should exist simple algorithms which allow for the determination of derivatives while following a random walk process. But this is exactly the argument we want to address in response to D. Creagh's request to "send short articles on topics which excite you".

The simplest random walk problem can be described by a system of m linear equations, which in matrix notation reads like: $x = a + Px$. In this equation the elements pij of P stand for the transition probability from all states j to state i, ai is the probability that a random walk starts in state i, and xi counts the number of times a state is visited.

It is not difficult to imagine how such a random walk problem has to be computed. But it is much less obvious that also the first- and higher order derivatives of the *xi*-s with respect to the *pij*-s can be sampled with a modest additional computing effort. In fact there are *m3* derivatives *ûxi /ûpij*. A detailed description of the algorithms and sampling procedures providing derivatives is outlined in: "Synopsis of Monte Carlo Perturbation Algorithms", by H. Rief, *J. Computational Physics*, 111, 1, pp 33-48, (1994). The concept can be extended to integral equations and therefore to particle transport problems as elaborated in the review: Stochastic Perturbation Analysis Applied to Neutral Particle Transport, by H. Rief, to be published in *Advances in Nuclear Science and Technology*, Vol. 23, 1995.

Now, why do we need derivatives ? They offer the possibility to perform a posteriori perturbation calculations by the use of a multivariate Taylor expansion and to analyze the stochastic simulation process in terms of additional criteria, such as: - the determination of the sensitivity coefficients - the estimation of the variance of the target quantities as a function of the uncertainty of the input parameters - the eventual adjustment of measured input parameters such that the discrepancy between measurements and calculations is minimized. But this is not all: Apart of differentiating with respect to parameters characterizing the system, like, for example material densities or (partial) cross-sections, etc., it is also possible to differentiate with respect to biasing parameters aiming at minimizing the variance in a non-analogue game. In this case we differentiate the second moment of the score with respect to the biasing parameters and extrapolate the dependence of the variance (essentially the second moment) from the biasing parameter(s) in a multivariate Taylor series. This requires in most cases the determination of higher-order derivatives to obtain a reasonable approximation of the curve or surface containing the minimum. The problem is formulated such that the particle in each of its random walk steps accumulates information on the derivatives, which later on are used to generate the variance profile of non-analogue games we intend to, but have not yet, played. This is similar to the construction of a response surface, a technique well known in sensitivity analysis. A paper dealing with this matter was submitted for publication: Optimisation of Non-analog Monte Carlo Games using Differential Operator Sampling, by P.K. Sarkar and H. Rief submitted for publication to *Nuclear Science and Engineering*, (1995). An example dealing with a particle deep penetration problem, shows that it is sufficient to run just one analogue case to find the biasing parameter which renders the minimum variance in a non-analogue game.

Is it black magic or does it open a new chapter in Monte Carlo ?

The National Network of Radiation Physics in Egypt

M A Gomaa
Chairman, 2nd Radiation Physics Conference
Head of Atomic Reactors Division
Atomic Energy Authority
Cairo, Egypt

The excellent planning for co-operation between the Atomic Energy Authority of Egypt and the Egyptian scientists from Universities and other Research Centres led to the formation of the Egyptian National Network of Radiation Physics (NNRP) in 1993, Radiation Physics Conferences and Seminars.

The Proceedings of the First Radiation Physics Conference held in Qena (near Luxor) was published in J.Rad.Phys. and Chem. in 1994. Other NNRP activities were published in the Egyptian Atomic Energy Series :

1. The First Seminar of Radiation Physics (Current Trends in Radiation Physics) was published as ARE-AEA Seminar Series –1 (1993)

2. The Second Seminar of Radiation Physics (The Role of Governmental and Non-governmental Organisations in Teaching and Development of Radiation Physics) was published as ASRE-AEA Seminar Series – 2 (1994)

3. The Third Seminar of Radiation Physics (Radiation Physics in Medicine) will be published in ARE-AEA Seminar Series – 3 (1995).

In the present issue of J.Rad.Phys. and Chem. the proceedings of the Second Radiation Physics Conference which was held at El-Menoufia University (Shebin El-Kom City – 80 km north of Cairo) is presented. In it the contributed papers are included. Furthermore, the invited papers of the Second Radiation Physics Conference will be published through the Information Press House of the Atomic Energy Authority of Egypt in 1995.

Two new functions will be carried out in Egypt in 1995 and 1996. These are :

(a) The Fourth Seminar of Radiation Physics (Radiation Protection Legislation in Egypt – the need to update, 11–12 November, 1995 and will be held in the National Centre for Radiation Research and Technology, Nasr City, Cairo

(b) The Third Radiation Physics Conference is to be held at El-Menia University (13–17 November, 1996). El–Menia City is 400 km south of Cairo and 500 km north of Luxor. This Conference is organised by the Atomic Energy Authority and El–Menia University of Egypt. The Arab Atomic Energy Agency and the Nuclear Research Centre of Libya are sponsoring it.

Members of NNRP (Egypt) support Training programs held in Cairo such as

(i) training programs of the Middle-East Regional Centre for Radioisotopes, mainly in radiation protection and dosimetry

(ii) training programs of the Atomic Energy Authority, mainly on the peaceful uses of ionizing radiation and radiation protection and awareness programs

(iii) training programs of the Arab Atomic Energy Agency in the peaceful uses of nuclear energy and radiation protection.

Alongside the Radiation Physics Seminars held in Cairo, pioneers of radiation and nuclear physics such as Prof M El–Nadi, Prof M Mokhtor and the late Prof F El-Bedawa as well as members of the International Radiation Physics Society were awarded the NNRP (or AEA) medal or shield for the Advancement of Radiation Physics.

The National Network of radiation physics is co-sponsored by the IRRA and IRPS as well as the Egyptian Society for Nuclear Sciences and Applications (ESNSA).

A New Problem in Radiation Protection: The Auger Electron Effect

Lars Persson
Division of Nuclear Safety, IAEA
PO Box 100, A–1400, Vienna, Austria

Introduction

The Auger electron effect is a well known atomic shell effect important in radiation protection related to work in radiobiology, radiophysics and nuclear medicine. Auger electron emission from an atom may occur when an atomic shell electron vacancy is created, induced by processes such as electron capture decay, internal conversion in gamma radiation decay processes of nuclei or photoelectric interaction with external radiation. The residual atom is then highly excited. De-excitation takes place with the initiation of one or more atomic vacancy cascades leading to the emission of x-rays or Auger electrons. (Bergström and Nordling (1965)).

An important quantity related to the Auger electron effect is the fluorescence yield ω which is defined as the ratio of the number of x-rays emitted to the number of primary vacancies created in the atomic electron shells. The fluorescence yields in the K–, L– and M–shells versus the atomic number are given in a report by Hubbell (1989). For high atomic numbers, the x-ray production dominates and for low atomic numbers the Auger electron process dominates.

For absorption of radiation in the K–shell in elements of very low atomic numbers (as in living cells), emission of Auger electrons are dominating (only a few per cent K x-rays). The energy of an Auger electron emitted can be calculated according to a formula also given by Bergström and Nordling (1965). As an approximate value for radiation protection purposes, the formula $E_A = E_x - E_Y - E_Z$ can be used, where E_A is the kinetic energy of the Auger electron emitted, E_x is the binding energy of the inner shell electron, and E_Y, E_Z are the binding energies of outer shells involved in the Auger emission process.

The so-called Coster–Kronig and Super–Coster–Kronig transitions are a class of Auger transitions in which the initial hole is transferred to an atomic shell having the same principal quantum number (Sastry et al (1988)).

The electron capture and internal conversion modes of nuclear decay create an inner atomic shell vacancy which initiates a complex cascade of atomic de-excitation processes, whereby numerous very low energy Auger electrons are emitted within ~ 10^{-15}s leading to a highly charged state of the residual atom. If the Auger emitter is a part of a molecule, the high positive electric charge accumulated on the emitter during its decay has a profound effect on the chemical structure of the molecule since the process of charge redistribution is violent and may lead to severe disruption of chemical bonds. This is of great importance when the chemical structure plays a functional role in the biological context.

Most of the Auger electrons have energies ranging from a few to several hundred electron volts and correspondingly are of short ranges in tissue (some nanometres). The dense shower of Auger electrons that are emitted deposits energy in the immediate vicinity of the decay site, resulting in high local energy densities that can exceed those along the tracks of densely ionizing alpha particles (Howell et al (1993)).

Radionuclides which emit a high proportion of Auger electrons are widely used in nuclear medicine (eg ^{99m}Tc, ^{123}I, ^{201}Tl) and biomedical research (eg ^{51}Cr, ^{125}I). Natural radioactive isotopes exist with Auger electron emissions (eg ^{40}K). In nuclear weapon debris inter alia the isotope ^{55}Fe with a half-life of 2.7 years exists (Persson (1969). In the nuclear energy cycle inter alia the isotope ^{65}Zn with a half-life of 244 days exist (Atkinson et al). As mentioned in a letter by Van Middlesworth (1993) slightly elevated levels of ^{125}I have now been detected in animal and human thyroids in England. Calculation of the equivalent dose for incorporated radionuclides considering the Auger electron effect is thus important for a correct risk assessment.

Many chemical substances are transformed in nature by biological processes before they reach humans. Even in the human body, metabolic processes can alter substances before they enter the organs to which they present hazards. It is important to recognize that the chemical form of the Auger emitter determines the subcellular localization and distribution, and the biological effects accordingly. Although the cell nucleus, in general, is radiosensitive, the DNA is regarded as the likely molecular target. Each Auger emitter is also unique by virtue of its nuclear decay scheme.

The decay of radionuclides following their administration to patients leads to the deposition of energy within various organs, tissues, cells and subcellular fractions. The calculation of the does is, therefore, an important activity in nuclear medicine. Such dose estimates are used to determine the health risk involved and the amount of a radionuclide that should be administered to a patient for therapy or diagnostics.

Further reviews of the Auger electron effect is available in the proceedings of a workshop held in 1987 in England (Baverstock and Charlton (1988) and Persson (1994)).

The Second International Symposium on Biophysical Aspects of Auger Processes was held at the of Massachusetts in 1991 (Howell et al (1992)). The next symposium in this series will be held 24–25 August, 1995 at the Department of Radiation Physics, University of Lund, Sweden.

Biophysical Aspects

Hofer (1992) reviewed the papers presented at the symposium at the University of Massachusetts and reported: "Another important trend in the field is the increasing emphasis on medical applications of Auger emitters, both in diagnostics and in therapeutic nuclear medicine. Many different Auger emitters are currently used for diagnostic applications, and the situation is further complicated by the fact that these radionuclides are administered in a great variety of chemical configurations. The problem of assessing risks is by no means trivial and will require considerable additional experimental and theoretical work. At the same time, Auger emitters hold great promise in radionuclide therapy of cancers, if (and that is still a very big if) suitable methods for selective, or at least preferential, radionuclide delivery to cancer cells can be developed. All these applications depend on the unique decay and dose distribution characteristics of Auger emitters which permit differential radiation exposures of subcellular and even submolecular sites".

To postulate radiation action mechanisms and to test them by Monte Carlo simulation, a complex computer model was developed (Pomplun and Terrisol(1994)) consisting of major components for the generation of a radiation spectrum, biomolecular structures and electron track structures in liquid water. The radiation source ^{125}I was employed. It is a suitable test radiation due to its exactly localized position in the DNA molecule and high biological toxicity as the consequence of the emission of short-ranging Auger electrons. Auger emitting isotopes in different chemical compounds are useful as probes in studying subcellular and sumolecular systems.

Medical applications

There appears to be two important issues for Auger electron emitters in medicine. At the root of both is that characteristic of the Auger electron decay : the highly localized irradiation of the surrounding volume. Considerable exposure is delivered to the part of a cell or a macromolecule which is in the vicinity of the decaying nuclide. This on the one hand brings about a problem in risk estimation for nuclear medicine and on the other hand promises of a selective attack on cancer cells : "molecular surgery".

The following isotopes (normally bonded in a chemical compound) are of special interest in nuclear medicine as Auger electron emitters : ^{51}Cr, ^{55}Fe, ^{67}Ga, ^{75}Se, ^{77}Br, ^{80m}Br, ^{99m}Tc, ^{110}In, ^{111}In, ^{114m}In, ^{123}I, ^{125}I, ^{145}Sm, ^{193m}Pt, ^{195m}Pt and ^{201}Tl (Baverstock and Charlton (1988); Goodman et al (1989); Hofer (1992)). Some of these radionuclides also have a role in cancer treatment.

The most widely used and studied Auger electron emitter is ^{125}I. This radionuclide decays with a half-life of 60 days by electron capture to ^{125}Te and emits a shower of an average of about 20 Auger electrons per decay. The great majority of these electrons has energies of less than 1 keV and, consequently, deposit their radiation energy in the immediate vicinity of the decaying nuclide (1–125nm). Unlike x-rays, Auger electron emitters decaying within a cell or a biological macromolecule cause highly differential radiation exposure of the labelled site, with only minor irradiation of distant regions.

Auger cascades can also be produced by irradiation with monoenergetic photons having energies just above the K-shell absorption peak of the chosen target atom and by thermal neutron bombardment of ^{157}Gd (Martin et al (1988)).

Dosimetry of Auger electrons

Leichner (1991) discussed the absorbed dose specification in nuclear medicine. He commented among other things on limitations of the calculations of "S" factors (absorbed dose per unit cumulated activity) : "A further shortcoming is related to the dosimetry of Auger electrons. The underlying assumption for "S" factors is that the absorbed dose in individual cells is the same as the average absorbed dose in an organ. In reality, the absorbed dose in cells is strongly dependent on whether or not an Auger electron emitter is internalized in the cells. In general, the local absorbed dose resulting from Auger electrons with subcellular ranges can be much greater than the average absorbed dose. Tabulated "S" factors for radionuclides such as ^{111}In, ^{123}I, ^{125}I and ^{201}Tl should, therefore, be used with caution".

Experiments with living cells

Rao et al (1989) have studied the radiotoxicity of ^{125}I–iododeoxyuridine (IUdR) by the determination of the survival of spermatogonial cells of mice. Narra et al (1991) studied the same issue by investigating the survival of pre-implantation mouse embryos. Iododeoxyuridine is a thymidine analogue and incorporates into the DNA of proliferating cells. ^{125}I incorporated into DNA was as effective as densely ionizing 5.3 MeV α–particles from ^{210}Po in reducing the sperm head population in mice. The embryo survival curves show that the dose at 37% survival is only about 0.15 Gy for ^{125}IUdR, whereas for 662 keV gamma rays from ^{137}Cs, it is 1.75 Gy. These results are consistent with the observations in mouse testis and cultured cells and point to the need for assessing the radiation risk from incorporated Auger electron emitting radionuclides based on their sub-cellular distribution. Also ^{125}I-labelled DNA binding agents other than ^{125}IUdR have been shown to cause severe damage to the DNA molecule, as discussed by Ludwikow et al (1992).

The deletereous effect of ^{111}In in vivo was reported by Rao et al (1988), where the cytotoxicity of some indium compounds was studied in mouse spermatogenis.

The relative biological effectiveness of three ^{99m}Tc radiopharmaceuticals (pertechnetate, pyrophosphate and hydroxyethylene diphosphate) was investigated using the spermatogenesis in mouse testis as the experimental model, and spermatogonial cell survival as the biological end point. The results showed that the radiotoxicity of ^{99m}Tc in mouse testis is essentially similar to that of low-LET radiations (ie RBE=1). The result is understood from a detailed analysis of the distribution of the activity and of the electron spectrum. From these experiments the authors conclude that the Auger electrons emitted in the decay of ^{99m}Tc radiopharmaceuticals are not capable of causing extreme toxicity in vivo. They note that the results provide further support for ^{99m}Tc as the radionuclide of choice for imaging in nuclear medicine.

Narra et al (1991) state that it is not uncommon for women in the very early stages of pregnancy unknowingly to undergo procedures involving radionuclides. Although there are some general exposure guidelines for the first trimester, there are no criteria specifically for the pre-implantation period. The results using pre-implantation mouse embryos may thus serve as a step to establish radiation protection standards for incorporated radionuclides during the pre-implantation period in humans.

Radiation protection organizations : the Auger effect

ICRP discussed the Auger electron effect in its Publication No 60 (ICRP (1991)). On page 6, paragraph 26, they state : "Auger electrons emitted from nuclei bound to DNA present a special problem because it is not realistic to average the absorbed dose over the whole mass on DNA as would be required by the present definition of equivalent dose. The effects of Auger electrons have to be assessed using the techniques of microdosimetry (see Annex B, paragraph B 67)".

Paragraph B 67 in Annex B reads: "It has recently been appreciated that the Auger electrons may have values of RBE considerably higher than those for other electrons. In cases where the radionuclide does not penetrate the cell, the Auger electron emitters are very inefficient in producing biological effects because of the short range of the low energy electrons. For those Auger electron transmitters incorporated into DNA, the RBEs for a range of endpoints, including cell killing, were found to be between 1.5 and 8 (Kassis et al (1988)). For Auger emitters incorporated into DNA, such as ^{125}I, much higher RBEs values of 20–40 have been found for endpoints such as cell transformation (Chan and Little (1986)) and calculations of energy deposition patterns have confirmed that those high values of RBE are to be expected (Charlton (1988); Baverstock and Charlton (1988))".

In the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (BRSS – 1944), it is stated that Auger electrons emitted from nuclei to DNA are excluded from the radiation weighting factor of value 1 for electrons of all energies with the remark that special microdosimetric considerations apply.

The British National Radiological Board (NRPB) has discussed Auger electron emitters in a "Board statement on estimates of late radiation risks to UK population" (NRPB (1993)). NRPB says: "In summary there is some evidence for the increased effect of Auger emitters even when dosimetry is based on the estimation of doses to the cell nucleus. Much detailed information is required to assess the risk. The concentration of the Auger emitter within the cell nucleus is dependent on its chemical form. If the Auger emitter is not attached to the chromatin then estimation of dose to the nucleus seems an adequate representation of the biological effect. If the Auger emitter is attached to the chromatin then the biological effect is characteristic of a high LET response and a further factor is required. This factor depends on the physical decay scheme and is therefore nuclide dependent. For the present there are insufficient data available to make any general recommendations for calculating doses. In the case of a few Auger emitters some allowance may need to be made for this heterogeneity of distribution in calculating doses for assessing risk".

In the 1993 Report of UNSCEAR to the Un General Assembly it is mentioned that at low doses ^{125}I incorporated into DNA is extremely effective at inducing oncogenic transformations (UNSCEAR (1993)).

Equivalent dose for Auger electron emitters

Howell et al (1993) state: "Depending on the subcellular distribution of the radionuclide, the biological effects caused by tissue-incorporated Auger emitters can be as severe as those from high–LET alpha–particles. However, the recently adopted recommendations of the International Commission on Radiological Protection (ICRP (1991)) provide no guidance with regard to calculating the equivalent dose for these radionuclides. The present work, using spermatogenesis in mouse testis as the experimental model, shows that the lethality of the prolific Auger emitter ^{125}I is linearly dependent on the fraction of the radioactivity in the organ that is bound to DNA. This suggests that the equivalent dose for Auger emitters may have a similar linear dependence. Accordingly, a formalism for calculating the equivalent dose for Auger emitters is advanced within the ICRP framework".

The equivalent dose in an organ or tissue T is defined as $H_T = w_R \bullet D_{T,R}$, where w_R is the radiation weighting factor and $D_{T,R}$ is the absorbed dose in the tissue from radiation R. For a mixed radiation field, such as those generated by many radionuclides including Auger emitters,

$$H_T = \sum_R w_R \bullet D_{T,R} \quad (1)$$

Howell et al (1993) propose that the equivalent dose specifically for the Auger electrons may be expressed as:

$$H_{T,R(Auger)} = (1 + f_o (w_{R(Auger)} - 1)) \sum_{R(Auger)} D_{T,R} \quad (2)$$

where f is the fraction of the radioactivity in the organ bound to DNA. This equation limits appropriately at $f_o = 0$ and $f_o = 1$. Although this equation is fundamentally sound, separation of the biological effects of the Auger electrons from those of other radiations emitted by the radionuclide is not possible experimentally because the observed RBE values are for the composite spectrum of emissions. Therefore, it is difficult to assign a value to w_{Auger} that corresponds directly to measured RBE values.

In Report No 3 of American Association of Physicists in Medicine – AAPM – Nuclear Medicine Task Group No 6 (Humm et al (1994)) methods of Auger electron dosimetry at the DNA, cellular, multicellular and organ level are discussed. This Task Group recommends a preliminary value of 10 be used for $w_{R(Auger)}$ in equation (2) to obtain the deterministic equivalent dose H_T for prediction of therapeutic outcome and a value of 20 for stochastic effects. The dose equivalent calculated with these radiation factors must be modulated by experimentally determined subcellular distributions. It should be noted that equation (2) is based on experiments where ^{125}I is covalently bound to DNA in the cell nucleus. When the Auger emitter id localized in the nucleus but not covalently bound to DNA, somewhat lower RBE values may be expected. The equivalent dose from the Auger electrons may then be a factor of 2 lower.

Conclusions

The AAPM Task Group (Humm et al (1994) recommends use of radiation weighting factors for cellular and organ dosimetry in conjunction with equivalent dose formalism that takes the subcellular distribution of the Auger emitter into account. Based on the currently available radiobiological data which show that the effects caused by the Auger emitters are similar to those of incorporated alpha emitters, a preliminary radiation weighting factor of 10 is recommended for deterministic effects (ie, cell survival) and a value of 20 is recommended for stochastic effects (ie, risk assessment for cancer induction). The dose equivalent calculated with these weighting factors must be modulated by experimentally determined subcellular distributions.

The relative biological effectiveness of three ^{99m}Tc radiopharmaceuticals (pertechnetate, pyrophosphate and hydroxyethylene diphosphate) was investigated by Narra et al (1994) using the spermatogenesis in mouse testis as the experimental model, and spermatogonial cell survival as the biological end point. The results showed that the radiotoxicity of ^{99m}Tc in mouse testis is essentially similar to that of low–LET radiations (ie RBE=1). These results provide further support for ^{99m}Tc as the radionuclide of choice for imaging in nuclear medicine.

The results using pre-implantation mouse embryos may serve as a step to establish radiation protection standards for incorporated radionuclides during the pre-implantation period in humans (Narra et al (1991)).

There are good reasons to consider the Auger electron effect not only in medical radiation protection of patients but also in the context of annual limits of intake for workers and the public. It may also be prudent to review the current equivalent dose estimates for radiopharmaceutical labelled with Auger electrons (Humm et al (1994)).

Auger emitting isotopes bonded in different chemical compounds may be useful as probes in studying subcellular systems (Pomplun and Terrisol (1994)).

Further experimental and theoretical, radiobiological research in the field must be undertaken. Inter alia studies of chromosomal aberration mutations and cell transformations, making animal carcinogenic experiments and mathematical modelling are important for a deeper understanding of the subcellular structures and also for the processes involved in the interaction of radiation with biological material.

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../ Calendar

CALENDAR

1995

July

10–14 *6th Int. Symp. on Meson-Nucleon Physics and Structure of the Nucleon*, Blaubeuren, Germany; R Bilger, Physikalisches Inst, Univ Tubingen, D-72076 Tubingen, Germany

17–28 *School on Non-accelerator Particle Astrophysics*, Trieste, Italy; (ICTP)

23–27 *X-ray Centennial*, Boston, MA, USA; R Burke, Health Physics Society, 8000 Westpark Drive, Suite 130, McLean, VA 22102, USA

23-28 *American Crystallographic Association (ACA) Annual Meeting*, Montréal, Canada; Yvon LePage, e-mail: yvon@iecems.lan.nrc.ca

26 July –1 Aug *19th Int. Conf. on Physics of Electronic and Atomic Collisions (IUPAP)*, Whistler, BC, Canada; Int. Conf. Services, 604-850 West Hastings St, Vancouver, BC, Canada V6C 1E1

27–29 *Workshop on the Search for New Elementary Particles*, Trieste, Italy; (ICTP)

31 July –4 Aug *22nd Int. Conf. on Phenomena in Ionized Gases*, Hoboken, NJ, USA; W E Carr, Department of Physics, Stevens Institute of Technology, Hoboken, NJ 07030, USA

August

21–26 *8th Int. Conf. on Nuclear Physics (IUPAP)*, Beijing, China; Sun Zuxum, China Inst. of Atomic Energy, POB 275, Beijing 102413, China

27 Aug–9 Sept *11th Int. Conf. on Vacuum Ultraviolet Radiation Physics (IUPAP)*, Tokyo, Japan; T Ishii, Inst. for Solid State Physics, University of Tokyo, Tokyo 106, Japan

27 Aug-1 Sept *10th International Congress of Radiation Research*, Wuerzburg, Germany; GSF Research Centre, Congress Service, Neuherberg, Postfach 1129, D-85758 Oberschleissheim, Germany

28 Aug–3 Sept *New Trends in Quantum Field Theory (IUPAP)*, Sofia, Bulgaria; R Kerner, LGCR, Univesite Paris VI, 4 Pl Jussieu, Paris 75005, France

28 Aug–8 Sept *24th Int. Comm. on Cosmic Rays (IUPAP)*, Rome, Italy; N Iucci, Dipt di Fisica Generale, Univrsita degli studi "La Sapienza", P le Aldo Moro 2, 00185 Roma, Italy

September

10–15 *Optical Society of America 95 Ann.Mtg.*, Portland, OR, USA; (OSA)

11–15 *Int. Conf. on the Physics of Strongly Coupled Plasmas*, Binz, Ruegen, Germany; W Kraeft, Fachbereich Physik, Universitat Greifswald, Domstrasse 10a, D-17489 Greifswald, Germany

September (C'td)

11–15 *Gas Discharges and Their Applications*, Tokyo, Japan; GD95, Department of Electrical and Electronic Engineering, Musashi Institute of
Technology, 1-28-1 Tamazutsumi, Setagaya-ku, Tokyo 158, Japan

15-18 *10th Congress of Polish Society of Medical Physics*, Cracow, Poland; M Radwanska, e-mail: radwanska@novell.ftj.agh.edu.pl

20-23 *Roentgen Centenary Congress*, Wuerzburg, Germany; Kongress-Partner, Eberhardt-Gastell & Neumann GmbH, Bottenhorner Weg 16, D-60489 Frankfurt, Germany

25-29 *Roentgenstrahlung from the Universe*, Wuerzburg, Germany; X-ray Conference Secretariat, Max-Planck-Institut f. Extraterrestrische Physik, Postfach 1603, D-85740 Garching, Germany

12–21 *Fourth Oxford Summer School in Neutron Scattering*, Oxford, UK; Prof B T M Willis, Chemical Crystallography Laboratory, 9 Parks Road, Oxford OX1 3PD, UK

23–28 *Quantum Optics*, Davos Platz, Switzerland; (ESF)

October

8–13 *14th Int. Conf. on Cyclotrons and their Applications (IUPAP)*, Faure, South Africa; M Herbert, National Accelerator Centre, PO Box 72, Faure 7131, South Africa

23-28 *Roentgen Centennial*, Wuerzburg, Germany; E Umbach, Physics Dept, Univ. of Wuerzburg, Am Hubland, D-97074 Wuerzburg, Germany

30 Oct –1 Dec *School on Synchrotron Radiation in Science and Technology*, Trieste, Italy; (ICTP)

November

20–24 *Int. Conf. on Ultrafast Processes in Spectroscopy*, Trieste, Italy; (ICTP)

1996

January

18–25 *International Schools and Conference on X-Ray Analytical Methods (AXAA)*, Sydney, Australia; N Stephenson, AXAA '96 Secretariat, GPO Box 128 Sydney, NSW 2001 Australia

March

15–20 *Sixth Conference of Nuclear Sciences and Applications*, Cairo, Egypt; Prof Dr A I Helal, Atomic Energy Authority (ESNSAS) 101 Kasr El-Eini Street, Cairo, Egypt, Fax No. 00202 3543451

July

21–25 *X International Conference on Small-Angle Scattering*, Campinas, Brazil; Prof. Aldo Craievich, LNLS, Cx Postal 6192, 13081-970 Campinas, SP, Brazil

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