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OFFICE BEARERS : 1997 - 2000

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FROM THE EDITOR

Dudley Creagh

Here I am, writing the first Editorial for the first edition of the IRPS Bulletin for the New Millenium, and wondering what the future holds for us all.

It is clear that few, if any of us were actually BITTEN by the Y2K Bug. But I am thankful that governments were alert to, and acted on, the perceived threat.

First the good news. We have received a significant number of papers, reports, notices of meetings, from the members. Long may this trend persist!!

Now the bad news. There will be only three IRPS Bulletins this year because of the IRPS 8 Meeting in Prague.

Following on from that: this issue contains voting papers for both membership and constitutional amendments for the IRPS 8 Meeting.

IT IS VITAL THAT WE RECEIVE YOUR VOTING PAPERS SO THAT

THE EXECUTIVE COUNCIL MAY BEST REPRESENT MEMBERS' WISHES.

I hope to meet a large number of you at the IRPS 8 Meeting. The Executive Council will have a table in the poster area. Please come and chat with us.

Until then⟩

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REPORTS FROM MEMBERS

Richard Pratt Honored with Special Symposium

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In honor of **Richard Pratt's** transition to **Professor Emeritus** in April of 1999, a Special Symposium was organized by two of his former students **Lynn Kissel** and **Paul Bergstrom** and held October 30, 1999 in Thaw Hall at the University of Pittsburgh. The eight invited lectures were provided by a mix of former students, a current student, and by **Richard's** U.S. and international long-time radiation physics associates, all of whose lives and contributions have been enhanced by his association with them.

The Saturday morning session opened with a lecture by **Paul Bergstrom** (LLNL, former student) "Compton scattering: Some theory, some applications," followed by a lecture by **Odair Gonçalves** (UFRJ, Rio de Janeiro, Brazil) "Accurate Rayleigh differential cross sections for 60 keV photons - the Ag case." Following the sociability of the morning coffee break, the Symposium continued with a lecture by **Jonathan Carney** (current student) "Corrections to existing S-matrix calculations for scattering" and a lecture by **Mihai Gavrila** (Romania, now at FOM, Amsterdam; family exited Romania and reunited via efforts led by **Richard**) "Extreme relativistic Compton scattering from K-shell electrons. I. General theory" closing the morning session.

Following a deli catered lunch provided by the Physics Department, the afternoon session opened with a lecture by **John Hubbell** (NIST, Gaithersburg, Maryland) "X-ray cross sections and crossroads (the International Radiation Physics Society). Richard Pratt's contributions to both", followed by a lecture by **Joseph Macek** (University of Tennessee - Knoxville) "Harmonic oscillator Green's function." After a social break including a group photo, the session continued with a lecture by **Viorica Florescu** (Faculty of Physics, Bucharest, Romania) "Extreme relativistic scattering of photons from bound electrons. II. Computation and limiting cases." The concluding lecture was given by **Lynn Kissel** (LLNL, former student) "RTAB: The Rayleigh scattering CD-ROM database."

The above lectures will be published in a "**Richard Pratt** special issue" of Radiation Physics and Chemistry guest-edited by **Paul Bergstrom**. The anticipated publication date for this RPC special issue is August 2000.

In the evening following the Symposium **Richard Pratt** was further honored with the traditional University banquet, held in the William Pitt Union as arranged by **Judy Stern** (Assistant Chair, Department of Physics and Astronomy) and assisted by **Heidi Aufdenkamp**. Another behind-the-scenes person contributing to the success of the entire occasion was **Laura Paolicelli** who, in the face of competition from a home football game with Penn State, heroically found conveniently located hotel space for all attendees, some of us in the University Club for the full flavor of the academic milieu.

The banquet program, following a delicious meal, was chaired by **Frank Tabakin.** Besides the presentation of several appropriate gifts including a Hitchcock chair, the program included remarks by a number of the Symposium lecturers, also some University officials as well as other associates of **Richard's** representing his varied outside interests. Several of these testimonials mentioned **Richard's** enthusiasm and iron-man stamina as a serious hiker, on mountains and on other available terrain encountered on his extensive global travels. **John Hubbell's** remarks, focusing on **Richard's** central and nurturing role in the International Radiation Physics Society (IRPS), were concluded by **John** pulling his well-travelled harmonica from his pocket and playing The Happy Wanderer ("I love to go awanderin', along the mountain track, . . . ") in recognition of this particular facet of **Richard's** broad spectrum of on- and off-campus full-tilt activities. **Lynn Kissel's** remarks as a student and as a colleague, both poignant and entertaining, included the lasting lessons that he learned at the knee of the master and a candid look at **Richard's** "sainthood" possibilities.

The next day, Sunday October 31, 1999, **Richard** and **Ann Pratt** graciously hosted, with their gathered family, a brunch and open house in their home. In the afternoon, while **Richard** took **Odair Gonçalves** on a vigorous hike through some nearby wild area (we were impressed by **Richard's** high-tech and seriously engineered metal walking sticks), **Jean** and **John Hubbell** also took time out to enjoy the spectacular flower show then in progress at the Phipps Conservatory, compliments of **Ann's** Conservatory associate membership tickets. Regrouping in the evening, again at their Shady Avenue home, we were all relieved to hear **Richard** mention that he would be "back at his desk Monday morning" with the exception of a dental appointment, and later some observance of **Richard** and **Ann's** 41st Wedding Anniversary (married November 1, 1958). We hope that **Professor Emeritus Richard Pratt's** contributions (and stimulations, to his students and colleagues) to theoretical radiation physics, as well as his guiding hand on the International Radiation Physics Society, will continue for many years to come.

New PET Centre in Prague

Ladislav Musílek

Czech Technical University in Prague
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Brehova 7, 115 19 Praha 1, Czech Republic

The shortage of funds for health care in "post-communist" countries in Central Europe (not in absolute cost, but influenced mainly by rapidly increasing prices of medication) leads to only a slow introduction of modern, but expensive, diagnostic and therapeutic methods.

In contrast to the traditional imaging methods such as X-ray, CT, MRI, angiography or ultrasonography, positron emission tomography (PET) has the advantage that it offers not only anatomical images of body structures, but is also able to depict pathological biochemical processes earlier than they result in structural changes. It only brings a low radiation load for patients, comparable with common radiodiagnostic examinations. On the other hand, the procedure is quite expensive, e.g. in the U.S.A. it costs about $2000, due to the initial price of a PET camera for imaging, a cyclotron for the production of radiopharmaceuticals, and the operational costs of a cyclotron. Nevertheless, in the final result, using PET can save funds for the health care system because of the better diagnostics especially in oncology, cardiology and neurology.

The first PET centre in the Czech Republic was recently opened at the Department of Nuclear Medicine of the Hospital "Na Homolce" in Prague. It was founded, and is operated, by the joint effort of the Hospital "Na Homolce" and the Institute of Nuclear Research in Rez near Prague. The initial project was supported by the International Atomic Energy Agency. The centre is located in a separate building in the area of the hospital and is divided into two parts: the production of radiopharmaceuticals is part of the Institute of Nuclear Research, and the diagnostics is part of the Department of Nuclear Medicine of the hospital.

The centre is equipped with the cyclotron *Cyclone 18/9* (Ion Beam Applications s.a., Belgium), accelerating protons up to 18 MeV and deuterons to 9 MeV. Two fluorine and one oxygen target are installed at the accelerator, target material of the first one being water enriched to more than 95% by ^{18}O for production of ^{18}F, target material of the second one being gaseous nitrogen for production of ^{15}O. Together with the radiochemical modules for processing the irradiated target materials to the desired chemical forms, laboratories and operational areas, this part of the PET centre forms an independent working place, which is able to supply radiopharmaceuticals not only to the adjacent diagnostic part, but also to departments in other hospitals. The number of permanent staff is 5 persons. This production part of the centre, as designed, can serve as a model for other countries of similar size as the Czech Republic.

The diagnostic part is equipped with the PET Camera *Siemens/CTI ECAT EXACT*. It is part of the Department of Nuclear Medicine, which has a staff of 4 physicians, 4 other university graduated specialists (physics, dosimetry, radio-pharmacology, immunoanalyses) and 10 nurses and a laboratory staff. However, they do not deal only with PET, but also with the conventional scintigraphy, immunoassays, etc.

As PET enables us to understand better the essence of various functional diseases, it has a great research potential as well. Therefore, there are some plans to use the centre also as a research laboratory. The possibilities of joint projects with universities and research institutes are very prospective.

More information about the PET centre and the hospital generally can be found on the web site:

http://www.homolka.cz

XCOM: Photon Cross Sections Database — now also for Windows

Leif Gerward, Nicolas Guilbert,
Klaus Bjorn Jensen and Henrik Levring

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The XCOM program can generate cross sections and attenuation coefficients on a standard energy grid, spaced approximately logarithmically, or on a grid selected by the user, or for a mix of both grids. The program provides total cross sections and attenuation coefficients as well as partial cross sections for the following processes: incoherent scattering, coherent scattering, photoelectric absorption, and pair production. For compounds, the quantites tabulated are partial and total mass interaction coefficients. The total attenuation coefficient is equal to the sum of the interaction coefficients for the individual processes. Total attenuation coefficients without the contribution from coherent scattering are also given, because they are often used in gamma-ray transport calculations.

The interaction coefficients and total attenuation coefficients for compounds and mixtures are obtained as sums of the corresponding quantities for the atomic constituents. The weighting factors, that is, the fractions by weight of the constituents, are calculated by XCOM from the chemical formula entered by the user. For mixtures, however, the user must supply the fractions by weight of the various components.

Written in 1987, XCOM was intended to be compiled and linked on a main-frame computer, or run on a personal computer using DOS. Today, however, most PC users are accustomed to Microsoft Windows. Therefore, we thought it worth while to develop a Windows version of the much liked and reliable XCOM program. As it turned out, it was no easy task, and most of the original code had to be rewritten. Anyway, we are now testing a beta version of the program, which we call WinXcom.

Like the original DOS version, WinXcom can be used to calculate photon cross sections for scattering, photoelectric absorption and pair production, as well as total attenuation coefficients, in any element, compound and mixture, at photon energies from 1 keV to 100 GeV. The WinXcom output table can be exported as an Excel worksheet, a delimited text file, or a delimited text in the Windows Clipboard.

For the time being, the beta version of WinXcom is available at :

http://www.intellix.com/klj-private/winxcom.htm

We would like to invite the readers of the Bulletin to test WinXcom. Any comments or suggestions are welcome. Please, send them by e-mail to the following address:

gerward@fysik.dtu.dk

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MEMBERS' PAPERS

A.P. Bagshaw and M.J. Farquharson :
X-ray Fluorescence as a Technique to Determine the Extent of the Body's Iron Stores

Lief Gerward :
The Discovery of Gamma Rays

IRPS
ELECTION
INFORMATION

INTERNATIONAL RADIATION PHYSICS SOCIETY

ELECTION OF COMMITTEE MEMBERS

to be held at ISRP-8, Prague, 4 - 9 June, 2000

The slate arrived at by the Election Committee for the election of members of the IRPS Committee, after circulating members (IRPS Bulletin Vol 13 No 4), is :

President : M.J. Cooper

Secretary : R.H. Pratt

Treasurer : A. Ljubicic

Regional Vice Presidents :

Western Europe : F. Rustichelli

Eastern Europe : L Musilek

F.S.U. : A.E. Shikanov

North America : J.H. Hubbell

South and Central America : A. Paschoa

South East Asia : S.C. Roy

North East Asia : Luo-Zheng Ming

Africa and Middle East : D. Jones

Australasia : D. Creagh

Councillors : M.J. Farquharson

D. McLean

L. Gerward

R.T. Mainardi

W. Gilboy (for one term of three years, to replace D. Creagh who would otherwise have had one remaining term as Councillor)

Continuing Councillors : T. Nakamura

A.M. Ghose

D.A. Bradley

No petition nominations (including signed consent forms) were received prior to the deadline, but write-in votes are still welcome, provided the voter knows a nomination consent form has been signed by the write-in candidate.

All Correspondence to :

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CHANGE TO CONSTITUTION

OUR SOCIETY PROPOSES CHANGES TO ITS CONSTITUTION

The IRPS Executive Council is proposing a number of immediate changes to our constitution which require the endorsement of our voting members.

A copy of our constitution is on this website *(Constitution* via Home page) and a small working group with Rex Keddy as its convenor is formulating suggestions for the revised constitution. If you have any suggestions please email him (**109ker@cosmos.wits.ac.za**).

In the meantime there are a number of changes which are necessary for the reasons explained below.

Members - please download and complete this page and return it with your ballot paper for the IRPS election.

- We want retiring officers and others concerned with the promotion of the society to be able to continue to play a recognized role in IRPS activities through membership of an Advisory Board chaired by the Immediate Past President. We propose a change to # 5.5 as follows:

  # 5.5 There shall be an Advisory Board for the Society, chaired by the Immediate Past President of the Society. Its members shall include all previous members of the Executive Council who are not currently serving, as well as othere designated by the Chair to serve during the term of the Chair. The Board shall take initiative in the promotion of the Society, subject to the Executive Council to which it reports, and respond to its direction

  Add to the end of the first sentence of # 7.2: "***and the Chair of the Advisory board***" so that the sentence reads :

  # 7.2 The Executive Council shall be composed of voting members consisting of
  (i) eight Executive Councillors who are elected by and from the General membership,
  (ii) the President, Vice-Presidents, the Secretary, and the Treasurer of the Society, and
  (iii) the Chair of the Advisory Board of the Society…..

  Please circle one of: ***AGREE*** ***DISAGREE***

- We wish to broaden the scope of the society to include "radiations" which are not described as "ionizing" : for example: lower energy electromagnetic radiations, such as those used in infrared spectroscopy and (nuclear) magnetic imaging. The required changes are the removal of the word "ionizing" from the preamble and # 2.1.

  Please circle one of: ***AGREE*** ***DISAGREE***

- We propose that full members of the Society (those who are paying the appropriate full-rate subscription) be entitled to use the letters MIRPS after their name if the so choose. The modification is to # 3.1.

  Full members whose dues are paid up are entitled to use the letters MIRPS (Member of the International Radiation Physics Society) after their name.

  Please circle one of: ***AGREE*** ***DISAGREE***

- With respect to nominations: at present our constitution (# 8.2) stipulates that additional candidates for election to office must be proposed, with their written consent, "by 5% of the membership of the Society". Because this number is not generally known, and in any event, may vary with time, we propose that ***"5% of the membership of the Society"*** be replaced by "***ten (10) full, paid-up, members of the Society."***

  Please circle one of: ***AGREE*** ***DISAGREE***

NEW MEMBERS, ADDRESS CHANGES

Welcome to New Members :

Dr MAHMOUD I ABBAS, *ITALY*	Dr (Mrs) ELIZABETTA GARGIONI *GERMANY*
Mr D N AVADHANI, *INDIA*	Ms KALOTINA GERAKI, *U K*
Mr AINARS BAJINSKIS, *LATVIA*	Mr VEERENDRA K MATHUR, *U S A*
Mr PATRICK J BYRNE, *U S A*	Dr PAULO R PASCHOLATI, *BRAZIL*

New Members' addresses are listed in the Contact Members' Details (click on country next to name)

Address changes of Members :

Dr PETER J BINNS, *now U S A*	Dr ROBERT MAYER, Jr, *U S A*
Dr STEVE BODDEKER, *U S A*	Dr LUC R M MORIN, *FRANCE*
Dr DAVID BRADLEY, *now U K*	Mr SERGIO A PEREIRA, *BRAZIL*
Mr I R ENTINZON, *UKRAINE*	Mr DIETRICH PLATTHAUS, *GERMANY*
Dr SCOTT M EPSTEIN, *U S A*	Ms MARIA ESMERALDA R POLI, *BRAZIL*
Mr CHAN-HYEONG KIM , *U S A*	Dr S RAMKUMAR, *now INDIA*
Dr GLADYS A KLEMIC, *ITALY*	Dr WILLIAM K WARBURTON, *U S A*
Mr ASLAM LONE, *CANADA*	

Members' new addresses are listed in the Contact Members' Details (click on country next to name)

X-ray Fluorescence as a Technique to Determine the Extent of the Body's Iron Stores

A. P. Bagshaw and M. J. Farquharson

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The aim of the work being conducted in the Radiation Laboratory at City University is to develop a technique whereby iron concentrations in human skin are measured *in vivo* using K-shell x-ray fluorescence (XRF). There are several diseases in which it would be advantageous to have a precise and accurate measure of the body iron burden, particularly one which would be non invasive and capable of regular repetition. In particular, there are several diseases in which patients are susceptible to a toxic build up of iron, known as iron overload, which can occur as a primary result of the disease itself or as a result of its treatment.

β -thalassaemia is an inherited form of severe anaemia which, untreated, is fatal within the first two years of life. As a result of an imbalanced production of the α and β globin chains that are needed to manufacture haemoglobin, the red blood cells of sufferers are smaller and less efficient than normal, and have a shorter lifespan. In order to try and compensate for this, erythropoiesis (red blood cell production) in the bone marrow is significantly increased, which leads to an expansion of the bone marrow volume and marked skeletal deformities and thinning of the bones. However, the demand for viable red blood cells is still not met, resulting in hepatic and splenic erythropoiesis, leading to severe enlargement of these organs. Death occurs as a result of cardiac failure or complications arising from repeated bone fractures.

The standard treatment for β -thalassaemia is regular blood transfusions which maintain the haemoglobin concentration at an appropriate concentration. These are necessary at intervals of 4– 6 weeks throughout the patient's life in order to avoid the complications arising from abnormal erythropoiesis. However, there is a problem associated with this treatment in that blood contains a large amount of iron, approximately 200 mg per 400 ml transfusion (Pallister 1998). The human body has very limited means of excreting this excess iron since it is generally concerned with conserving iron stores, and the percentage body iron turnover per day in humans is only 0.03 % (Porter 1996). As a result, there is an overwhelming build up of iron in the main storage sites, the liver and the spleen, as well as damage to the heart, pancreas and pituitary glands. The organ damage consequent upon iron overload is eventually fatal, unless treated with iron chelating agents such as desferrioxamine (deferoxamine, DFO, desferal). This drug must be administered continuously via subcutaneous infusion if the consequences of iron overload are to be avoided.

In order to observe the efficiency of the iron chelation it is necessary to gain access to a measure of the total body iron burden. Since the majority of storage iron is held in the liver (Fischer *et al* 1999), liver biopsy with iron determination via atomic absorption spectroscopy (AAS) is the current reference method. However, this is an invasive procedure and can only be performed approximately annually. Given the toxic effects of inadequate iron chelation, and also the toxic effects of providing an excess of desferrioxamine, which can include hearing loss, retinal abnormalities, changes in renal and pulmonary functions, neurological abnormalities and various bone disorders (Olivieri 1996, Hollán 1997), it would be advantageous to be able to monitor the level of storage iron more frequently and thus to maximise the efficiency of the chelation therapy. In addition, much work is currently underway to assess the viability of a new range of orally-active chelators, such as deferiprone (L1) and CP94 (e.g. Porter 1996, Olivieri 1996, Olivieri and Brittenham 1997), which also requires an accurate method of determining the extent of the body's iron burden.

Hereditary haemochromatosis is a condition in which iron overload occurs as a result of an increased and unregulated uptake from the small intestine. This process continues throughout the life of the patient and the clinical effects of iron overload generally become manifest after a few decades. The problems associated with iron overload are the same as those experienced by patients who have had multiple transfusions, but the treatment regime is somewhat simpler since, in the absence of anaemia, the regular removal of blood (phlebotomy therapy) is a viable method of reducing the amount of iron in the body. The prognosis for patients who follow a course of phlebotomy is good, and disease-related morbidity can be prevented. Given that this is the case, it is vitally important to detect the presence of the disease as early as possible, either by observing a genetic marker or by detecting the clinical manifestation of the disease, iron overload. To this end, it has been suggested that the screening of populations at risk is a viable proposition, using a measurement of the serum ferritin concentration as the primary screening process, with the diagnosis confirmed by DNA analysis and/or liver biopsy (Bassett *et al* 1997, McDonnell *et al* 1999). Ferritin is an iron protein complex and is the main form in which iron is stored in the body. A measurement of the serum ferritin concentration is not always a reliable measure of the body's iron stores since it is affected by the presence of infection, inflammation and liver disease. A direct measurement of, for example, the hepatic iron concentration would be advantageous, though a screening program must necessarily utilise a non-invasive modality, and again there is a need for a technique which can perform as reliably as liver biopsy but without the associated risks and discomfort.

Several techniques have been proposed. Among these are magnetic resonance imaging (e.g. Mavrogeni *et al* 1998, Bonkovsky *et al* 1999), biomagnetic susceptibility using a superconducting quantum interference device (SQUID) (Brittenham *et al* 1982, Fischer *et al* 1999) and nuclear resonance scattering (Wielopolski and Zaino 1992). However, none of these methods have been incorporated into widespread clinical use and for example in the case of biomagnetic susceptibility there are only three centres worldwide which have the equipment. The need exists for a relatively cheap and simple device which can provide an accurate measure of body iron, particularly in view of the fact that some of the highest incidences of β -thalassaemia are in poorer parts of the world which do not have access to the expensive equipment that would be needed for MRI or biomagnetic susceptibility measurements.

X-ray fluorescence analysis is another method that has been applied to this problem. As a result of the relatively low energy of fluorescent photons emitted from iron, the $K\alpha$ and $K\beta$ energies being 6.40 keV and 7.06 keV respectively, the penetration depth in tissue is small, of the order of a few millimetres. This means that a non-invasive measurement must be taken on superficial tissues such as the skin, and then linked with organs that are particularly vulnerable to the effects of iron overload. Gorodetsky and co-workers (Gorodetsky *et al* 1985, Gorodetsky *et al* 1990) took a series of *in vivo* measurements of the skin of patients with β -thalassaemia and found elevated concentrations of iron in comparison to control subjects. The levels detected were very low, and there was a large variation between patients: for example the measurements ranged from 5.6-14.0 parts per million (ppm) in normals and 13.7-150 ppm in thalassaemics.

More recently, Farquharson and Bradley (1999) developed a system which used a copper K-edge filter as a source of photons to excite skin phantoms. This has the advantage that the energy of the quasi-monoenergetic beam produced (8.4 keV) is very close to the energy of the K absorption edge in iron (7.11 keV), and thus the probability of a photoelectric interaction followed by the emission of a fluorescent photon is maximised. Gorodetsky *et al* (1985, 1990) used a monoenergetic source of 11.4 keV photons, at which energy the photoelectric cross-section is appreciably lower. Farquharson and Bradley (1999) demonstrated the feasibility of the technique using skin phantoms, but the question still remained as to whether the concentration of iron in the skin correlated with that in the liver and other organs which are particularly susceptible to the effects of iron overload.

This question was addressed by Farquharson *et al* (2000) using iron overloaded rats. Half of the rats were injected with iron dextran to induce iron overloading, and the other half acted as a control group. Of the iron overloaded group, half were treated with the iron chelator CP94. Liver, heart and spleen iron contents were determined via colorimetry with bathophenanthroline sulphonate as the chromogen reagent (Torrance and Bothwell, 1968). Samples of abdominal skin were examined using XRF with the experimental set up shown in *Figure 1*. As can be seen, a

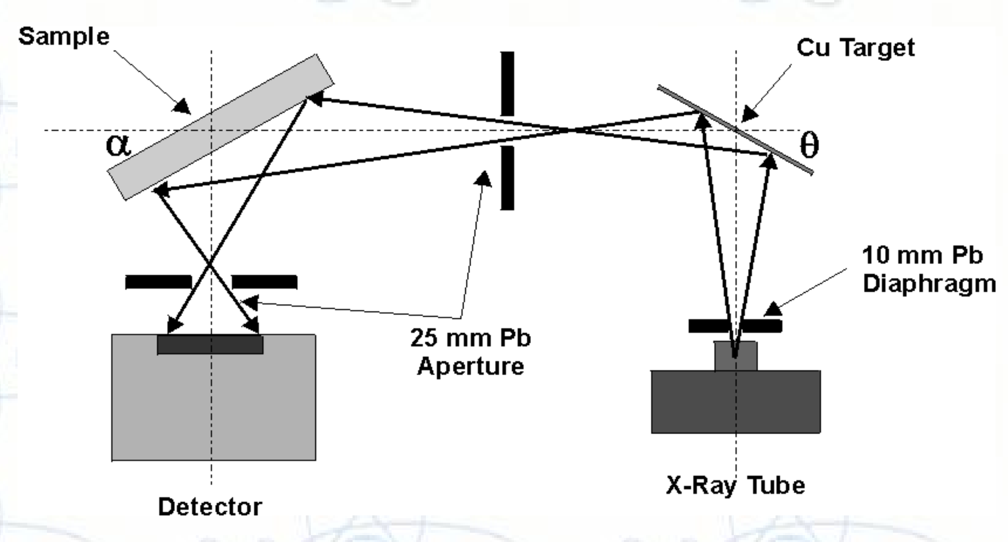

Fig 1 A schematic representation of the experimental setup

secondary copper target was used as the excitation source. The $K\alpha$ and $K\beta$ energies of copper are 8.05 keV and 8.90 keV respectively. The detector used was an EG&G Ortec SLP series Si (Li) detector with a crystal of diameter 16 mm and thickness 5.0 mm and a 0.05 mm beryllium window. A pulse shaping time of 6 μ s was used.

In order to provide quantitative measurements of the iron concentrations in the samples of rat skin, a series of skin phantoms were made, containing solutions of iron sulphate in varying concentrations. The amount of iron fluorescence detected from the phantom was then compared with the concentration of iron in the phantom, leading to *Figure 2*. Figure 2 in fact shows the ratio of the iron fluorescent peak area to the scattered copper peak area, which was done in order to take into account any fluctuations in the output of the x-ray tube during the course of the experiment. The scattered peak is composed of both coherent and incoherent components.

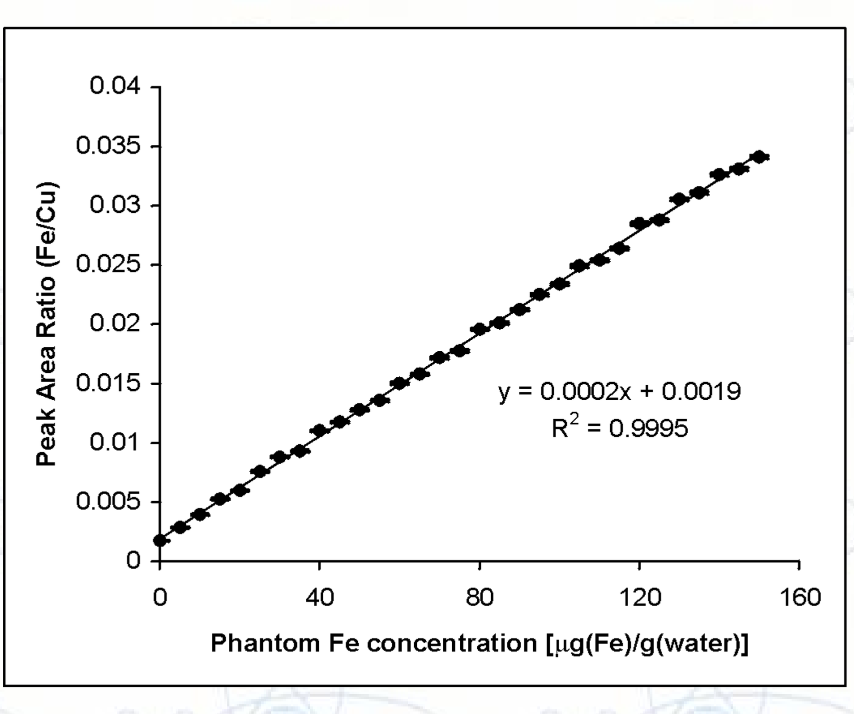

Fig. 2 The calibration curve linking the amount of iron fluorescence detected to the concentration of iron in the phantom

Measurements were then conducted on the skin samples, using exactly the same geometry, acquisition time etc. as had been employed for the calibration phantom measurements. *Figure 3* is the result of plotting the skin iron concentrations, measured by XRF, against the liver iron concentrations, determined by colorimetry. As can be seen, there is a good correlation ($R^2 = 0.86$) between the amount of iron measured in the skin and that found in the liver. There is some suggestion that a plateau exists i.e., that there is a maximum concentration of iron that can be accommodated in the skin, at approximately 100 μ g/g. It should be remembered that these measurements are taken on rats which have been severely iron overloaded, and that rats have a somewhat different response to iron than humans. The XRF measurements by Gorodetsky *et al* (1985, 1990) on the skin of thalassaemia patients extended to iron concentrations of 150 μ g/g without noting the presence of any such plateau. If there is a maximum concentration of iron that can be present in human skin, it must clearly be higher than 100 μ g/g, and may not be reached in clinical circumstances. Future work will examine this question by taking measurements on human skin, both *in vitro* and *in vivo*.

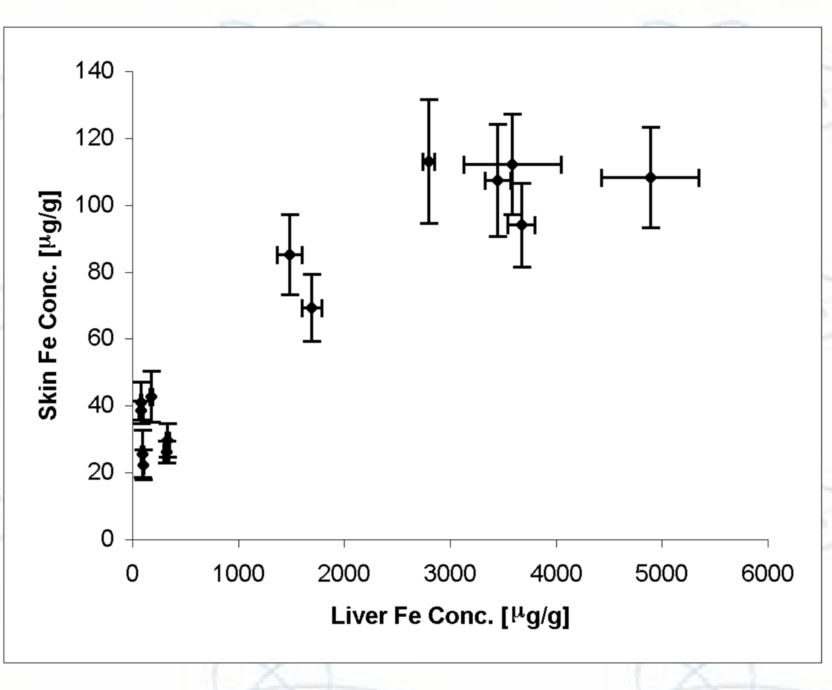

Fig 3 XRF skin iron measurement is plotted against the liver iron concentration

If an XRF-based system is to be a useful clinical tool in the treatment and diagnosis of iron overload, it must demonstrate its viability in three ways. Firstly, it must be capable of detecting iron at the very low concentrations that are found physiologically. This has been addressed by both Farquharson and Bradley (1999) and Farquharson *et al* (2000). Secondly, it must be shown that skin iron concentrations are correlated with those in the internal organs that are damaged by excess iron. This is the work that has been described here, and further details can be found in Farquharson *et al* (2000). The observation of such a correlation in rats is encouraging, since rats are much less conservative in their iron metabolism than humans i. e., they are able to excrete much more of the excess iron than humans, and a much smaller proportion goes directly into storage. The third point that must be addressed is the absorbed dose given to the patient during the course of an examination. This has been estimated at a maximum of 5 mSv for a system that was not optimised for dose (Farquharson and Bradley 1999), and it is likely that this figure can be lowered with appropriate modifications. Since the radiation will not penetrate below a few millimetres of skin the choice of an *in vivo* measurement site can be such that any radiosensitive areas are avoided.

In conclusion, this technique holds a great deal of promise as a method of providing a measure of the extent of the body's iron stores. The next step is to build a clinical prototype and take it into a hospital, where regular measurements can be taken on the skin of β -thalassaemia patients. In this way the usefulness of the technique can be truly assessed.

Further information on this subject can be obtained from the authors at

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m.j.farquharson@city.ac.uk.

The authors would like to acknowledge the U.K. Thalassaemia Society for their financial support in this study.

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The Discovery of Gamma Rays

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Radiation physics and chemistry flourished in the years around 1900. Wilhelm Conrad Röntgen's sensational discovery of X rays in 1895 was soon followed by Henri Becquerel's discovery of radioactivity and by J. J. Thomson's proof of the independent existence of negative electrons of small mass. Marie and Pierre Curie discovered the radioactive elements polonium and radium. A new kind of extremely penetrating rays, later called gamma rays, was observed by Paul Villard, but his discovery is almost never discussed in any detail. He stands, one might say, in the shadow of the giants Becquerel and the Curies.

Paul Villard was born in 1860 in a village near Lyon, France. In 1881 he entered the *École Normale Supérieure* in Paris. After his *agrégation*, which gave him the license to teach at any secondary school financed by the government, Villard taught at various lycées in the province, and finally at the Lycée of Montpellier. Here he became *Maitre de Conférences* at the University. He liked scientific research but soon felt that he had to work in Paris, which was the centre of physical science in France. Having a modest fortune that was sufficient for his needs, he asked for leave from his teaching position. He went to Paris where he enjoyed the hospitality of chemistry professor Henri Debray and his successors at the *École Normale*. Villard now devoted himself exclusively to science, spending the rest of his professional life in the chemistry department of the *École Normale* in *rue d'Ulm*.

Villard preferred independent research, and most of his papers are single-authored. He also had little concern for fame. Nevertheless, the *Académie des Sciences* awarded him its Wilde prize in 1904 and its La Caze prize in 1907. In 1908 he succeeded physicist Eleuthère Mascart as a member of the Academy. During the last years of his life, Villard was forced to spend extended periods of time outside of Paris because of his deteriorating health. He died in Bayonne on January 13, 1934.

Villard's earliest studies were in the field of physical chemistry, where he investigated the combination of water with various gases under pressure, forming hydrates of them. He published his first papers in the *Comptes rendus des Séancesde l'Académie des Sciences* in 1888 together with Robert Hippolyte de Forcrand. They repeated, with improved accuracy, some earlier studies on gaseous hydrates, but Villard soon reported on a further series of completely new hydrates, which had been considerably more difficult to produce. This work formed the basis for his doctoral thesis. In 1897 Villard gained access to a Crookes tube and started publishing a long series of papers on cathode rays and X rays. Villard's publication rate peaked in the years 1898-1900. During this period he published about ten major papers each year, including his two papers on radium radiation in 1900.

Radioactivity was a hot topic in Villard's day, and its investigation was pursued vigorously by a number of prominent scientists, such as Ernest Rutherford, Becquerel and the Curies. Transmission experiments indicated that the radiation emitted by radioactive bodies was heterogeneous. Rutherford named the then distinguishable types of radiation alpha and beta rays. At this time beta rays were more often studied than alpha rays because of their higher penetrating power and marked photographic action. Becquerel as well as Friedrich Giesel, Stefan Meyer and Egon Ritter von Schweidler demonstrated that radium beta rays are affected by a magnetic field. This brought out their strong resemblance to cathode rays.

Using his sensitive electrometer based on a piezoelectric crystal, Pierre Curie demonstrated that radium radiation consists of two distinct types: rays that are deviable in a magnetic field (beta rays), and rays that are non-deviable in a magnetic field (alpha rays). Transmission experiments by Marie Curie verified that the non-deviable rays are much less penetrating than the deviable rays. At this time, alpha rays were believed to be non-deviable by a magnetic field. Therefore, the two kinds of radiation, alpha and beta, were initially distinguished as non-deviable and deviable in a magnetic field.

The predictable identification of the deviable rays (beta rays) with cathode rays (electrons) required two more verifications. It was necessary to demonstrate that beta rays carry a charge of negative electricity, and that they are deflected by an electrostatic field. The Curies showed that the deviable radium rays impart a negative charge to an insulated conductor. Becquerel and Ernst Dorn independently verified the electrostatic deflection. Thus, beta rays were definitely identified with cathode rays, *i.e.*, it was proved that they are streams of rapidly moving, negatively charged electrons. For the velocity of the beta particles Becquerel got an astounding figure, between one-half and two-thirds of the velocity of light.

The Curies also observed some chemical effects produced by radium rays. They found that the rays emitted by highly radioactive salts of barium are capable of converting oxygen into ozone. They also observed a coloring action of the rays on glass and on barium platinocyanide commonly used for fluorescent screens. These results evoked Villard's interest because he had made similar observations with X rays. Villard's interest in radioactivity was now aroused, and he wanted to compare the reflection and refraction properties of cathode rays and beta rays. As it turned out, he would make an unpredictable discovery.

Paul Villard presented his paper, "Sur la réflexion et la réfraction des rayons cathodiques et des rayons déviables du radium," at the Monday session of the Paris *Académie des Sciences* on April 9, 1900. It follows from the title that Villard originally set out to study the deviable rays (beta rays) but his work led to his discovery of a new kind of penetrating rays. The description of his experiment is hard to follow without a diagram, but none is supplied. Villard addressed himself to a few scientists who were familiar with his experimental methods and he considered a verbal description perfectly adequate.

Villard emphasized that the deviable rays (beta rays) behave in all respects like cathode rays and that he wanted to measure the refraction of these rays. During the course of his work, Villard noticed that in almost every experiment the photographic plate revealed traces of a non-refracted beam, which obviously had been propagating in a straight line. This beam was superimposed on the refracted beam, making it difficult to interpret the photographs. Next, Villard tried to deflect the non-refracted rays in a magnetic field, but they were unaffected. Moreover, these rays were penetrating enough to affect the photographic plate protected by several layers of black paper as well as an aluminium foil. The rays were even able to traverse a 0.2-mm thick lead foil when placed in the beam.

The Curies kindly placed a much stronger radium sample at Villard's disposal, and three weeks later he presented new and more detailed results on the radium rays to the *Académie des Sciences*. His comparative study of the penetrating power of beta rays and his new type of rays, "Sur le rayonnement du radium," was read by Academy member Jules Violle at the Monday meeting on April 30, 1900. Villard's experimental arrangement was about the same as in his first radium experiment. The radiation from the radium sample was collimated by a long groove in a lead block and sent consecutively through two photographic plates stacked on top of each other. The deviable rays were bent in a magnetic field before hitting the photographic plates.

Villard reported that the first photographic plate showed traces of two distinct beams. One had been deflected by the magnetic field and broadened. The other had propagated along an absolutely straight line and produced a sharp impression. On the second plate there was only one trace, that from the non-deflected beam. It produced an impression that was as sharp and intense as on the first plate. It was even more visible because of the lower background radiation on the second plate. The plates were made of glass, and because of the grazing incidence the non-deflected beam had traversed 1 cm of glass before reaching the second plate. It followed that the non-deflected rays were able to penetrate at least 1cm of glass without any noticeable attenuation. Even a lead foil, 0.3mm thick, was found to attenuate the rays only slightly. Villard appears already to have associated the penetrating radiation with X rays. He concluded that the "X rays" emitted by radium had a considerably larger penetrating power than the deviable rays (beta rays).

Less than three weeks later, Villard expressed himself more boldly. At the Friday meeting of the *Société francaise de physique* on May 18, 1900, he demonstrated that radium emits rays that are non-deviable and extremely penetrating. These new rays, said Villard, were different from the radium rays observed so far. He went on to suggest that the extremely penetrating rays, discovered by him, were a kind of X rays. Furthermore, as he pointed out, the readily absorbed radium rays (alpha rays) were analogous to the non-deviable cathode rays (positive ions or *Kanalstrahlen*) previously observed by J. J. Thomson, Wilhelm Wien and others. The deviable rays (beta rays) had already been shown by Becquerel to be identical to a stream of electrons. Villard concluded that "on retrouverait ainsi les trois rayonnements des tubes de Crookes," *i. e.*, the three kinds of radiation (ions, electrons and X rays) known from experiments with cathode-ray tubes were all present in radium rays. Thus, from the beginning, Villard gave a correct interpretation of the three components of radium rays. Unfortunately, his discovery was largely overlooked by his contemporaries.

Villard performed his radium experiments under the watchful eyes of Becquerel. In fact, both men reported on transmission experiments with radium radiation at the April 9, 1900, session of the *Académie des Sciences*. Becquerel found it necessary to repeat Villard's experiment, and he delivered his comments three weeks later at the April 30 meeting. He disputed the apparent refraction of beta rays. Regarding the very penetrating rays, he simply denied their presence, arguing that the existence of these rays could not possibly have escaped attention in the experiments carried out by him or the Curies. Gradually, however, Becquerel had to accept the experimental facts. The Curies seemed to treat Villard's findings with more interest. As mentioned above, they placed a stronger radium source at his disposal, thus enabling him to produce more detailed and reliable observations. They also supported his interpretation of the penetrating rays as a kind of X rays.

Contrary to common belief, Villard did not introduce the designation "gamma rays." It is characteristic of the weak contemporary interest in these penetrating rays that they went unnamed for nearly three years. The name gamma rays was probably invented by Rutherford, but I have been unable to determine where they are explicitly named. Rutherford is still using the descriptive form "rays nondeviable in character, but of very great penetrating power" in the January 1903 issue of the *Philosophical Magazine*, but in the subsequent February issue, he introduces the trio alpha, beta and gamma. Marie Curie notes in her doctoral thesis that one can distinguish between three types of radiation, which are denoted by the letters alpha, beta and gamma, *following the notation of Rutherford*.

At first sight, it seems surprising that no one apparently took much care in 1900 and the following years of Villard's new kind of very penetrating rays. Rutherford measured the absorption of gamma rays in various materials, but for the time being did not pay much attention to these new rays. Turning to the alpha rays, Rutherford discovered their electric and magnetic deviability and proved that they consist of positively charged particles. From measurements of their charge-to-mass ratio, the alpha particles were provisionally identified as positive ions of hydrogen or helium. They finally were established as helium ions. Rutherford recognized that the alpha particles, since their mass is much larger than the mass of the beta particles, carry virtually all of the energy released in radioactive processes. Therefore he considered alpha rays more important than beta and gamma rays.

Consequently, he concentrated his research on the investigation of alpha particles. His studies culminated in the transformation theory of Rutherford and Frederick Soddy of 1903, and in the alpha -scattering experiments by Hans Geiger and Ernest Marsden, which led Rutherford to postulate the existence of the atomic nucleus in 1911.

Although studies of alpha rays yielded remarkable results, beta rays continued to attract considerable interest. Becquerel's numerical result for the charge-to-mass ratio of the beta particle was adequate for its interpretation as an electron and, if not at first very accurate, was soon improved upon by other experimenters. Walter Kaufmann was even able to show that its mass increases with increasing velocity of the particle.

Thus prominent and influential physicists and chemists were busy investigating alpha and beta rays (particles), yet they paid little attention to Villard's discovery of gamma rays. The available experimental possibilities for investigating gamma rays were limited, and their nature was difficult to determine. Marie Curie included a gamma-ray radiograph in her doctoral thesis, thereby demonstrating a potential application of Villard's discovery. She also noted, however, the weak contrast between bone and soft tissue in gamma radiographs, and the long exposure times required. It was much easier and faster to produce X-ray radiographs, and gamma rays remained a scientific curiosity for many years.

Apart from the limited experimental techniques available, a major reason for the small interest in gamma rays was that they apparently did not fit into contemporary views in radiation physics and chemistry. After J. J. Thomson's proof of the independent existence of the electron of small mass in 1897, and in particular after his measurements of its charge and mass in 1899, contemporary scientists focused much of their interest on the material nature of atomic radiations. The view that atomic radiations are material and particulate proved to be successful in interpretating the nature of cathode rays, and it continued to deliver remarkable results when applied to alpha and beta rays. That picture was disturbed with gamma rays, which did not seem to fit into this established view of radiation and matter.

The electromagnetic wave nature of X rays was firmly established in 1912, when Max von Laue conceived the idea of employing a crystal as a space diffraction grating for X rays. The successful realization of this idea by Laue and his assistants Walther Friedrich and Paul Knipping opened up a wide field of research. In the hands of William and Lawrence Bragg, father and son, X-ray diffraction soon became a powerful tool for crystal-structure determination, but also for X-ray spectroscopy. It would not be long before Rutherford applied crystal-diffraction techniques to confirm the wave nature of gamma rays. He and E. N. da C. Andrade first determined the wavelength of relatively soft gamma rays. Later, they employed an ingenious transmission method to measure the small angles of reflection (about 1.5°) of harder gamma rays. Thus, it was finally established that gamma rays as well as X rays are electromagnetic radiations of short wavelength. Meanwhile, high-voltage X-ray generators had made it possible to produce X rays with wavelengths in a range overlapping those of gamma rays, the only distinction between the two types of radiation being their origin. A few years later, Arthur Holly Compton's studies of the scattering of X rays led to the concept of X rays acting as particles. Thus, it was shown that X rays and gamma rays can indeed be viewed as streams of particles or quanta moving with the velocity of light. These particles, however, are not massive electrons but light (*sic*) quanta of zero rest mass (photons).

After publishing his two papers of 1900 on his discovery of gamma rays, Villard made no further studies of them. Was he disappointed by the little interest that his discovery aroused in the contemporary scientific community? In particular, was he disappointed by the reluctant acceptance of his results by Becquerel? Whatever the case may be, Villard decided to withdraw from the highly competitive arena of research in radioactivity and to devote his efforts to the more familiar cathode rays and X rays. Villard also developed an interest in the aurora borealis whose streamers are caused by the interaction between charged particles and molecules in the upper atmosphere and have some bearing on the electric discharges in a rarefied gas in a cathode-ray tube.

By necessity, but also following his own inclination, Villard constructed all of his experimental equipment himself. He devised several instruments useful for practising radiologists. The idea of using the ionization of air as a measure of the output of an X-ray tube was suggested by Villard in 1908. The principle laid down by Villard became internationally recognized twenty years later, when the roentgen (r) unit of radiation exposure was recommended by the Second International Congress of Radiology in Stockholm in 1928.

Today, the name of Paul Villard has disappeared almost without a trace. Nevertheless, as I have shown here, Villard made important contributions to radiation science and technology. In particular, many of his practical inventions had a lasting impact. Villard also made a crucial contribution to radiation science when he discovered gamma rays. However, the nature of these rays unfolded over several years through the work of several people. This clarifying process had to await the development of new concepts, such as the quantum theory of radiation and the existence of high-frequency electromagnetic waves.

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