the assessment of bodily contamination

The assessment of organ and body burdens resulting from the intake of radioactive contaminants is and remains one of the most difficult components of an adequate programme of radiological surveillance of workers under normal and accident conditions.

The IAEA, in co-operation with the World Health Organization and the International Labour Organization, organized a symposium on the assessment of radioactive body burdens in man, at Heidelberg in the Federal Republic of Germany, in May 1964. There has been much progress since then, but many basic difficulties remain.

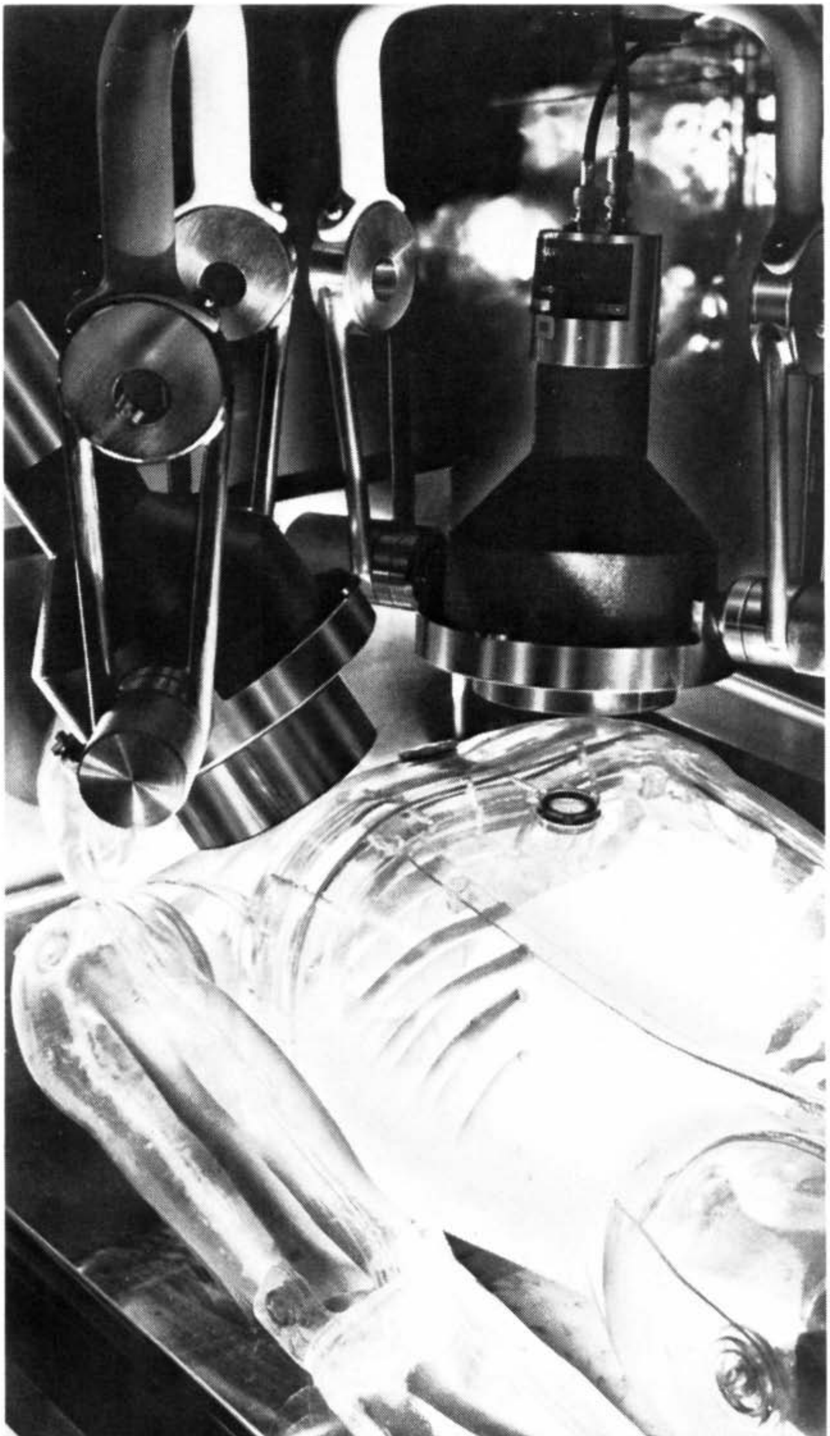
As this issue of the Bulletin went to press more than 130 scientists from member States of the IAEA and WHO were meeting in Stockholm, Sweden, to consider again the assessment of radioactive organ and body burdens, at a symposium organized jointly by the two organizations to bring up-to-date and to extend the results reported at the 1964 meeting.

The papers presented and a record of the discussions at this second symposium will be published in a few months. One paper prepared for it illustrates the nature of the problems encountered in this type of work — and highlights sharply the need for extreme care in handling radioactive materials. It must be emphasized that a case such as that reported here is possibly unique in the combination of circumstances which occurred.

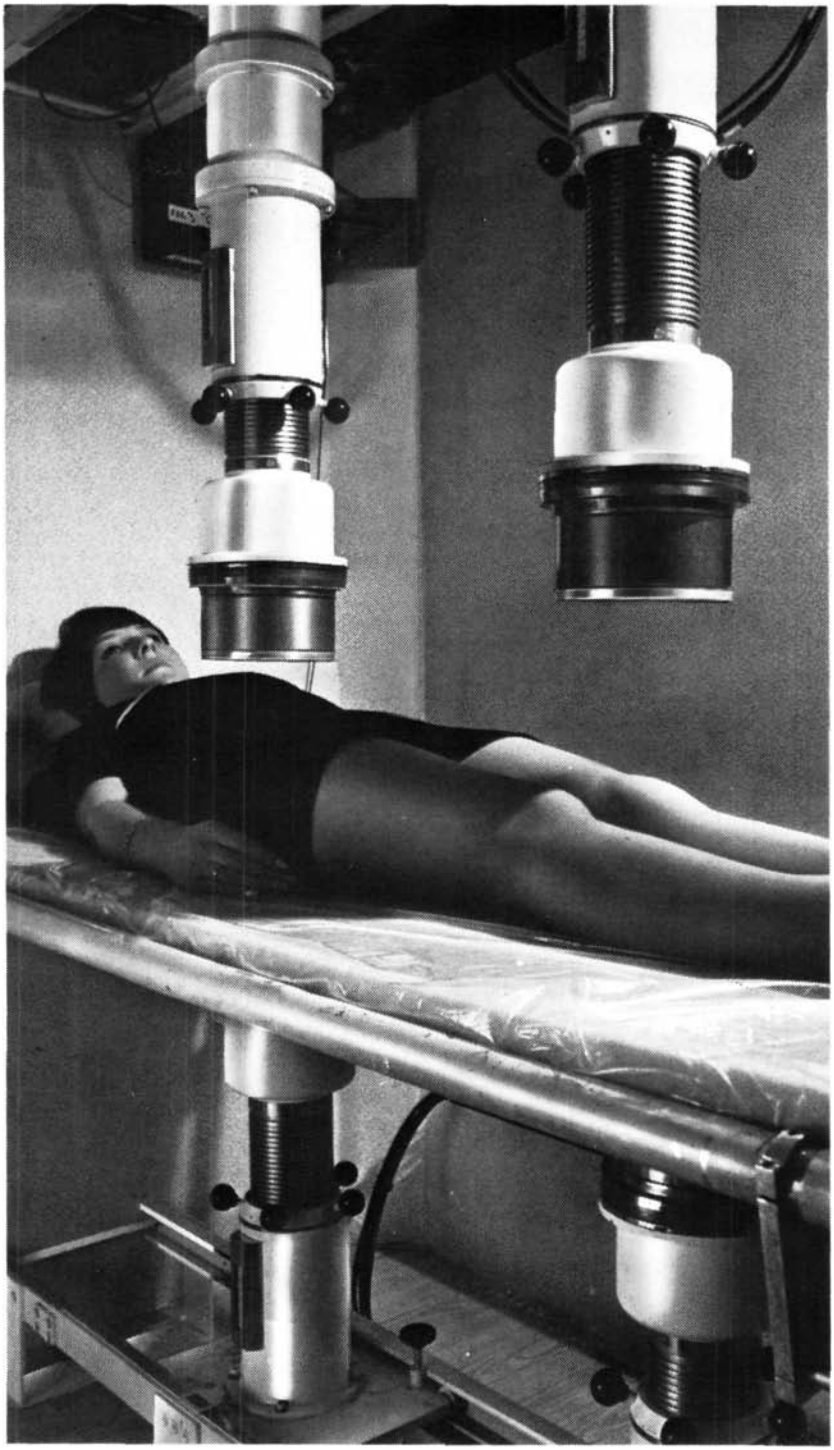
The legacy of the past

The paper, prepared by J.Rundo, A.T. Keane and H.A. May, of the Centre for Human Radiobiology, Radiological Physics Division of the Argonne National Laboratory, in the United States, describes the measurement of americium-241 in a ten-year-old boy. The story is all too simple.

"For a period of 3 months in 1964 a scientist worked in the detached garage of his home with a source of americium-241 of supposed strength about 10 mCi," the authors write. "The americium was reported by the supplier to be safe and not to release activity on smearing. The scientist's four-year-old son, 'R', followed the proceedings attentively.



A man-sized plastic model containing a human skeleton, which can be fitted with simulated lungs or liver containing known amounts of radioisotope in order to calibrate the counting devices shown at the top of the photograph.
This "phantom" was constructed as part of a programme designed to ensure the safety of radiation workers at Mound Laboratory, Miamisburg, Ohio. Photo: USAEC



Equipment used in the measurement of the radioactive content of the body, part of that used by the Health Physics and Medical Division of the United Kingdom Atomic Energy Authority. Photo: UK AEA

"In February 1970 alpha-particle contamination at the scientist's new place of employment was identified as americium-241 and its origin was eventually traced to contaminated furniture and fittings in his new home. Body radioactivity measurements at a nearby research institute demonstrated the presence of americium-241 in all members of the household, but at levels of concern only in the scientist and his son (then aged 10)."

The authors made two series of measurements on the scientist and his son, in April 1970 and in August 1971, using both scintillation detectors and a proportional counter. They made, as a part of their investigation, a series of studies of scattering and absorption, using an actual source of americium-241 and "not unreasonable" tissue equivalents.

A very approximate value for the body content of the boy was calculated from measurements using a scintillation counter and placement of the subject in a tilting chair, with potassium-40 used as an internal standard. They had no calibration for potassium for a subject as small as this, so had to assume a value for the potassium content of his body — 70 g, or 0.20 per cent of his body weight. Making various assumptions for attenuations in the body of gamma rays of differing energies, the body content of americium-241 was calculated to be 60 nCi. "But it must be remembered that counting efficiency is dependent on distribution in the body, and while potassium is primarily in soft tissue americium is a bone seeker. It is doubtful if this estimate is reliable to better than a factor of two."

When the subject visited the investigators again in August 1971 they were able to make measurements with him lying in an arc of radius 1.5 m, using a large thin sodium iodide crystal. Calculation on this occasion gave an estimated content of 38 $\pm$ 2 nCi [$\pm$ standard statistical error only]. Yet another series of measurements gave a value of 42 nCi in April 1970; yet another 24 nCi. It emerged from analysis that apparently three-quarters of the total content of americium was in the upper half of R's body. If the distribution of americium was uniform throughout the skeleton — which the authors say is "a major assumption of questionable validity" — this suggested that as much as half the total content could be in the soft tissue, presumably in the liver and/or lung.

"There are unsatisfactory features to the interpretation of the measurements made *in vivo*," they write. "Is the subject's body content 24 nCi or 40 nCi? Did it decrease between the two series of measurements as indicated by the decrease in the counting rates, or did re-distribution due to skeletal growth cause this? Did... exploratory chelation therapy play any part in this? These are questions which we would like to answer, but are unable to answer at the present time. Apparently the measurement of americium-241 *in vivo* is by no means straightforward... It is hoped that the presentation of these phenomena may be of assistance to others in the field who have not had occasion to observe them."

A case such as this is extremely rare, and it should be stressed again that it has no implications for the public safety. The nuclear industry in general has an extremely good safety record.

The historical background

Karl Z. Morgan, Director of the Health Physics Division of the Oak Ridge National Laboratory, USA, in an introductory review paper, recalls that although in the early period following the discoveries of Roentgen and Becquerel there were many individual efforts to set radiation protection standards, there were no serious efforts by organized groups until about 1920. The British X-ray and Radium Protection Committee presented its first measures for radiation protection in 1921, but did not suggest a value of tolerance dose. Most early suggested tolerance doses were based on some fraction of the dose estimated to result in a skin erythema.

Recommendations to limit the internal dose of radionuclides were later in developing ; the first recorded fatality due to radium in the radium industry was reported in 1925, and it was not until 1941 that an advisory committee of the National Council on Radiation Protection and Measurements (NCRP) established a maximum permissible body burden of radium as 0.1 μg. This committee reported: "When deposits of radium are large, the damage is chiefly to the skeleton followed by damage to the white and red corpuscles resulting in a leukopenia or anaemia or both. This has happened with deposits of from 12 to 100 μg of radium." At that time it appeared there would be a factor of safety of 10 to 100 between the recommended permissible body burden of ^{226}Ra and the level which would cause significant damage. The report went on to point out that small deposits of radium in the bone remain there almost indefinitely and can lead to crippling bone conditions which may progress to a malignancy, and stated "It is therefore essential to avoid all ingestion or inhalation of radioactive luminous compounds and to test workers periodically for exhaled radon in the breath ... It is, therefore, important to keep well below the tolerances stated to insure safety." Morgan notes that although values of tolerance dose or maximum permissible exposure to external sources of ionizing radiation have changed many times, "this first maximum permissible total body burden of 0.1 μg of ^{226}Ra has stood the test of time, and perhaps will continue in use in the new International Commission on Radiological Protection handbook, which is now in preparation."

The ICRP handbook on internal doses has been under review for some years, and is to be published in a revised form as *Handbook on the Dosimetry of Radionuclides Within the Body* early in 1973. The most important change planned for this new revision, said Morgan, was the introduction of the concept of dose commitment: a maximum permissible annual dose commitment corresponded to exposure at the maximum permissible concentration of the radionuclide of interest for one year, and in such case the integrated dose to 50 years corresponded numerically to the maximum permissible annual dose, MPAD. New information and recommendations will also be included.

Which standard to use?

"One of the most perpetual and persistent problems faced by the health physicist is the fact that there are radiation protection standards of many levels of importance, and persons who use these standards often fail to distinguish between the primary standards and radiation protection guides (secondary, tertiary, quaternary, etc., standards). In many cases, so much emphasis is placed on the enforcement of one or more radiation protection guides and they are taken in such a literal sense that there is failure to meet the primary or basic radiation protection standards. Often, members of the public and, worse yet, contractors and top administrators focus their attention so sharply on certain of the radiation protection guides that they never realise or they completely forget that these guides are of value and satisfy the requirements of a safe operation only insofar as they assure compliance with the primary radiation protection standards. The impression is given that so long as these secondary and tertiary standards ... are met, no further surveillance is required or no concern need be expressed as to whether there has been adequate compliance with the primary standards...

"For example, a given operator may have a false sense of security such that he feels quite assured of a safe and satisfactory performance if it can be shown that the concentration of radioactive liquid waste at the point of discharge and mixing in a nearby river is never more than 1% of the MPC for any combination of the radionuclides involved. Any smugness on the part of such an operator is unwarranted, however, if he loses sight of the fact that values of MPC are never better than tertiary standards.

"If there are critical pathways for certain of these radionuclides, for example, such that they are concentrated in plankton or algae by a factor of 1000 and then concentrated in edible portions of certain fish by a factor of 10, there probably is non-compliance with the primary standard. The management of a chemical plant would be completely irresponsible if it attempted to assure the public of the safety of its operation solely on the basis that the level of ^{131}I as measured at the boundary of its plant never exceeded 1% of the tertiary MPC standard. It would not be conducting an acceptable operation if no further investigations were made of the critical pathways and possible reconcentration of this ^{131}I in the thyroids of critical segments of the population. For example, ICRP and several writers have emphasized that ^{131}I maintained at 10% of the occupational MPC over the pasture of a dairy farm near the boundaries of such an operation could pass through the food chain from the grass to the cow to the milk and to the thyroid of the six-month-old child in such a manner that the ICRP primary standard or annual dose limit of 0.3 rem to the thyroid of the child could be exceeded by one or more orders of magnitude."

Morgan gave it as his opinion that the symposium in Stockholm should emphasize that organ and body burdens were at best only secondary standards. It may be no cause for alarm if a radiation worker had a maximum permissible skeletal burden of ^{45}Ca as defined in the relevant ICRP publication, *and* it could be shown that this radionuclide was distributed in the matrix of the skeleton in such a manner that the dose to the active bone marrow and/or other tissues of the bone had not, and would not as a consequence of this organ burden, exceed 10% of the primary basic standards of the ICRP. One of the first questions raised should be "What is the critical tissue and what dose will it receive in any year or during a 50-year period as a consequence of this organ burden?" or, in the assessment of the risk to this employee, "What is the organ burden and at what rate is it being eliminated from the critical organ and the body?" Much of the dose to the skeleton may be wasted in that it is delivered to inactive (non-mitotic) mineralized portions of the bone and to portions of the bone that are not considered critical in terms of tumor induction. A similar case could be developed with respect to ^{239}Pu and its concentration in lymph nodes in non-mitotic fibroitic tissue; risk in this case might be considered very small and readily acceptable. On the other hand, it might leak slowly into the blood and the circulating lymphatic system, and concentrate in other critical organs in such a way that the annual dose and/or dose commitment to these organs would be excessive.

The programme

During the symposium participants heard and discussed papers on direct methods of assessment, including the role of measurements on phantom (model) and human subjects in evaluating body burdens, and giving particular attention to the assessment of plutonium and uranium incorporation, shielding and the optimization of whole-body counting equipment; indirect methods of assessment, with particular attention paid to the measurement of contaminants in excreta ; body burden assessment programmes such as the work of measurement of internal contamination of radiation workers reported from the Bhabha Atomic Research Centre, India ; distribution studies and dosimetry; and the investigation of incidents such as that discussed briefly earlier in this article. The symposium ended with a panel discussion.

Participants in the meeting were expected from 23 countries; and from the Commission des Communautés Européennes, the European Nuclear Energy Agency, the Forum Atomique Européen (Foratom), the International Commission on Radiation Units and Measurements, the International Commission on Radiological Protection; WHO and the IAEA.