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Occupational health aspects of radioactive dusts

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OCCUPATIONAL HEALTH ASPECTS OF RADIOACTIVE DUST

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ABSTRACT

When working with radioactivity, both the employee and his/her employer feel the almost continuous gaze of public opinion and the government over their shoulder. Traditional reports about the diseases from which the early 20th-century scientists who discovered radioactivity were suffering, the acute and especially the later effects the A-bombs on Nagasaki and Hiroshima had on human health, and the even now still measurable effects on the health of citizens in the greater area surrounding Chernobyl after the nuclear accident there, all these facts have contributed to creating an image of disease and destruction for the concept of radiation.

To a corporate physician practising medicine in a nuclear environment, radiation is a relatively mild risk among the many factors that potentially threaten occupational health.
It is an integral part of corporate health care for which a company doctor can base his information on a great many certainties, so that he can usually give the employee in question fairly straightforward and unconditional advice.

The risk of exposure to ionizing radiation is very clearly defined:

- the degree of exposure can be determined with high precision;
- there is a great deal of knowledge on the dose-response relations between radiation and the various organs in the human body, which facilitates calculation and control of the health hazard;
- scientifically thoroughly motivated and universal limit values have in general been internationally established;
- regulations have been extended and provide assurance of intervention in case the employee's health is at risk in the short or longer term;

There are, on the other hand, countless influences to which employees are exposed and which the company doctor and safety expert can do relatively little about:
- for instance, exposure to most chemicals in the work environment can only be estimated;
- due to the multitude of constituent chemicals in each compound, there is far less knowledge of the pathogenic capacity of these compounds; early symptoms can be measured only to a limited extent and
- internationally different standards apply to many chemicals.

So far I haven't even mentioned the complex of factors determining occupational disease no. 1 in our western society, viz. stress and burn-out. Prevention of this keeps the bread of a large number of well-paid consultants buttered, but still the number of victims is only increasing.

Radiation protection science distinguishes between exposure to radiation from an external source and internal contamination. The main hazard to be discussed at this symposium is that of internal contamination due to radioactive particles.

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Such particles can penetrate the human body in three different ways, viz. through the skin, by way of ingestion and by inhalation.

As long as the human skin is intact, it is virtually impenetrable to most particles and materials. Contamination is possible only if there is a skin injury covering a large surface, or with certain skin diseases, like extensive eczema.

Ingestion and contamination through the skin have a lot to do with personal hygiene in general, eating, drinking and smoking habits, as well as careful treatment of wounds.

With exposure to dust, inhalation is the main route of potential contamination.

I'm pleased that English is the official language at this symposium, since the word "dust" fits the condition we are describing better than corresponding words in other languages.
Niosh, the US institute for working conditions, defines the word dust as follows: "solid particles formed during the use, processing, pressing, grinding, milling, springing and destruction of organic and anorganic materials, like ore, rock, metal, coal, corn or timber".

Diffusion of these particles in the medium, usually air, hardly ever takes place.

The main force to which the particles are subjected is gravity. The rate at which they fall to the ground, and hence their residence time in the air, is determined by mass and particularly by diameter. Obviously, these factors also determine the probability of particles being carried along in the airstream of inhalation.

Particles of a size exceeding 100, and even 25 μm, can hardly be inhaled.

In the respiratory system proper, the aerodynamic properties and the mass of the particles determine what happens to them, where they end up and how great the hazard is after inhalation.

It is therefore highly important to know the particle size distribution of the material penetrating the body, because this determines where the particles end up, how long they will remain inside the body and hence how harmful they are and what health hazard they represent.

The term aerodynamic diameter is here used to refer to a particle's aerodynamic properties and its mass. The behaviour of certain particles is described as if they were spherical particles with a density of 1. The resulting diameter is referred to as the Activity Median Aerodynamic Diameter (AMAD).

The ICRP has composed a model that reliably represents dust deposition inside the respiratory tract (see figure).

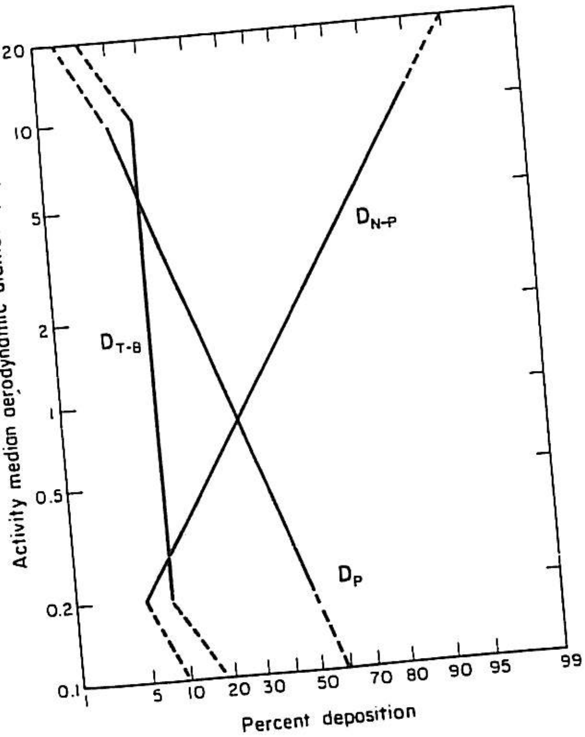

Figure: deposition fractions plotted as a function of AMAD (ICRP-30)
Dn-f = nasopharynxDt-b = bronchiDp = alveoli

The respiratory tract consists roughly of three compartments:

For the different particle diameters it has been established how they will be distributed over the various compartments of the respiratory tract.

- the nasopharynx; this is man's natural air filter. Particles exceeding 1 μm will deposit progressively here, while deposition is nearly 100% among particles exceeding 10 μm. The high humidity will also frequently cause hygroscopicity, which raises the deposition rate even further. Due to mucus production the residence time in this compartment is relatively brief, in the order of minutes. A certain part is carried out of the body, while another part gets into the gastrointestinal tract, where it can also have a toxic effect.

It should be observed here that heavy labour causes the volume of air inhalation and exhalation per minute to increase strongly (up to a factor of 5 or 10), and that respiration is then no longer through the nose only, but also through the mouth, increasing the air velocity so that larger particles can be inhaled and the filter action loses a great deal of its effectiveness.

- The windpipe and the bronchi; due to turbulence, diffusion and gravity, part of the dose (10-25%) deposits here, especially particles in the range of 0.2 - 20 μm; in healthy condition, the windpipe and bronchi have an effective dust removal mechanism, so that the residence time of dust here is also relatively brief, in the order of hours. However, smoking and e.g. bronchitis have an adverse effect on the dust removal mechanism.

- the alveoli, where actual gas change takes place; only particles that are smaller than 5 μm can reach this compartment. The smaller the particles, the higher the deposition rate, up to a maximum of 50% for the smallest particles in the range of 0.01 - 0.1 μm. The alveoli have only slow mechanisms for removing impurities (phagocytosis). Moreover, the impurities are subsequently stored in the pulmonary tissue for a long time. The residence time of the deposited particles here is in the order of weeks or even years.

This model can be used to calculate the dose resulting from an employee's exposure to a certain dust concentration of a certain level of radioactivity. Subsequently, the calculated dose can be reduced to established standards to determine if it represents a health hazard and, if so, to what extent.

The amount of radioactivity, the chemical and biological behaviour inside the body, the residence time (biological half-life) and the physical half-life eventually determine the dose to which the employee has been exposed.

The effects of radiation on tissues and organs can be divided into stochastic and non-stochastic effects.

Stochastic Effects
These are effects for which there is no threshold value. This concerns damage caused by ionizing radiation to the genetic material, resulting in tumour induction and/or defects transmitted to offspring. The most sensitive tissues are those that divide the most rapidly, such as bone marrow and the intestinal mucosa. Nevertheless, these are generally rather late effects: there could be an interval of 10 years or more between exposure and manifestation of the disease. Theoretically, it is a one-hit risk, meaning that a single energy quantum may suffice to cause the defect. The probability of tumour induction is however dependent on the total dose received over time. Recent research with e.g. rats indicates that the least tumour induction takes place when exposure is in the range of the background radiation naturally occurring on earth of 2.5 to 5 milliSievert/year. The induction seems ever less then compared to rats exposed to zero-level radiation. This implicates that the body seems to have resistance mechanisms to low-level exposure

Non-Stochastic Effects
These are the ionizing radiation effects resulting from damage to entire cells, causing failure of organ functions. An example is burns after acute irradiation of the skin. In such cases, a clear dose threshold can be given, below which the effect hardly ever occurs. The dose-response relation is translated in terms of the amount of tissue damaged, which is indicative of how serious the effect is. Non-stochastic effects usually occur after acute exposure to a relatively high radiation dose, since cells tend to recover in the course of time. We are then talking about doses that are 10 to 100 times larger than the annual dose resulting from exposure to natural background radiation.

With normal work in a dusty environment, there is a probability of receiving this type of dose only if any of a number of defined calamities occurs.

Other dust hazards:
Apart from any contamination hazard due to dust containing radionuclides, occupational exposure to dust in general involves certain health hazards.

Inert dust, i.e. dust containing no chemical compounds with known toxic effects, irritates the respiratory tract and the lungs upon inhalation. Especially people suffering from asthma or bronchitis will sooner suffer from this irritation, which causes coughing and shortness of breath, and in the long term leads to loss of elasticity of the lungs, which may result in disablement. The concentration in excess of which respirable dust can cause this effect is 5 mg dust per m^3 of air. Such a concentration is often present when dust is visibly floating in the air at the workplace.

There are many known substances that can cause irreversible damage to the lungs at far lower concentrations. Well-known examples include quartz, carbon and asbestos.

Asbestos, but also for instance polycyclic aromatics, can cause lung cancer after inhalation.

Exposure to dust present in organic compounds may cause chronic allergic pulmonary conditions, e.g. the baker's lung, barn allergy and the pigeon-breeder's lung.

The first strategy for control of dust problems at work is to ensure occupational hygiene. Following a thorough analysis of the exposure, both physically and chemically, the source should be minimized, screened from employees, e.g. by means of adequate personal protection gear. Our experience is that dust masks, certainly with heavy labour, often also in heat, cold and rough weather, are hardly ever sufficiently effective. Adequate protection of employees to residual dust exposure after appropriate measures have been taken at the source is generally achieved only by means of pressurized fresh-air systems.

If it turns out that there is actually an increased risk of exposure to radiation, explicit attention should be focused on medical supervision. Depending on the dose to be expected in a worst-case scenario, the radiation doctor and the radiation protection officer determine how frequently the employee in question should undergo medical checkups.

The purpose of medical checkups is:

- evaluation for each individual employee of health in relation to occupational hazards; detection of early symptoms of illness, and if possible starting of interventions to prevent worse effects;
- on the department and corporate level, testing of the control measures taken; do they have the desired effect on employees' health?
- detection of potential occupational diseases, also to evaluate working conditions in the industry, nationally or internationally.