16. BIOLOGICAL EFFECTS OF RADIATION EXPOSURE

16.1 RISKS FROM OCCUPATIONAL RADIATION EXPOSURE

The US Nuclear Regulatory Commission (NRC) requires that all persons working with radioactive material licensed by that agency be instructed in the health protection problems associated with the exposure to ionizing radiation. Similarly, the Occupational Safety and Health Administration (OSHA) requires instruction regarding the safety problems related to ionizing radiation exposure from x-ray devices, particle accelerators, naturally occurring radionuclides and accelerator-produced radioactivity. The US Environmental Protection Agency (EPA) in its radiation protection guidance for occupational exposure urges that workers be clearly informed of the biological implications of radiation exposure. It is intended that the following information will enable you to develop an attitude of healthy respect for the risk associated with radiation exposure rather than an unnecessary fear or lack of concern.

16.2 BACKGROUND INFORMATION

A measure of the biological damage sustained by tissue due to ionizing radiation is expressed by the tissue's dose equivalent (often referred to by just "dose"), the traditional unit of which is the rem. The dose equivalent is used to indicate the radiation dose due to internal radioactive contamination as well as external exposure. The dose pattern from organ to organ that results from internal radioactivity is normally very uneven. A computational method of handling non-uniform organ and tissue doses is the effective dose equivalent (EDE). A computed EDE, obtained by adjusting (weighting) designated organ doses according to the organ's relative sensitivity to harm by radiation, is a single quantity that indicates the potential harm or risk of the non-uniform dose pattern.

The total effective dose equivalent (TEDE) represents the sum of the deep dose due to external radiation and the EDE due to internal contamination.

To provide some perspective regarding the total effective dose equivalent, the natural "background radiation" level (due primarily to (a) radiation reaching earth from outer space, (b) the radioactive content of all terrestrial materials and (c) exposure to naturally occurring radon gas) results in a total EDE to all persons in the US that averages 0.3 rem (300 millirem) per year.

The biological effects of ionizing radiation can depend, among other factors, on: the type of radiation, the amount of the dose and the rate at which it is received, the type of tissues irradiated, and the age and sex of the exposed person. The biological damage is primarily due to the fact that the charged particles (ion pairs) that result from ionization, particularly in the water of body cells, yield highly reactive free radicals. The radicals then readily interact with molecules in the irradiated cells to break chemical bonds or produce other chemical changes. The resultant biological effects can be classified into three categories:
• **somatic** — effects occurring in the exposed person. The manifestation may be **prompt** or **delayed**. The period of time between exposure and demonstration of the delayed effect is referred to as the **latent** period.

• **genetic** — abnormalities occurring in the future children of exposed persons and in subsequent generations.

• **developmental or teratogenic** — effects observed in children who were exposed during the fetal or embryonic stages of development.

At the low levels of occupational exposure it is difficult to demonstrate the relationship between dose and effect. The changes induced by radiation often require many years or decades before being evident and, thus, a very long follow-up period is necessary to define risks. Studies of human populations exposed to low level radiation are the appropriate basis for defining risk. Yet the number of such investigations, from which the relationship between radiation dose and response can be determined, is limited, the best being those of the A–bomb survivors in Nagasaki and Hiroshima. Accordingly, there is considerable uncertainty and controversy regarding the best estimates of the radiation risk of low level doses.

### 16.3 SUMMARY OF CURRENT RADIATION RISK ESTIMATES

As used in this section, "risk" is the probability or chance of severe harm or death from radiation exposure.

#### 16.3.1 Somatic Effects

The somatic effects of interest are cataract and cancer induction.

**Cataract Induction** — The lens of the eye differs from other organs in that dead and injured cells are not removed. Single doses of several hundred rem have induced opacities that interfere with vision within a year. When the dose is fractionated over a period of a few years, larger doses are required and the cataract appears several years after the last exposure. The 1990 BEIR Report (ref. 1; a report prepared by a special committee of the National Research Council) concludes that **cataract induction should not be a concern** for the doses currently permitted radiation workers.

**Cancer Induction** — **Cancers** arising in a variety of organs and tissues **are thought to be the principal somatic effect of low and moderate radiation exposure**. Organs and tissues differ greatly in their susceptibility to cancer induction by radiation. Induction of leukemia by radiation stands out because of the natural rarity of the disease, the relative ease of its radiation induction and its short latent period (2–4 years).

However, the combined risk of induced solid tumors exceeds that of leukemia. It is currently thought that cancer induction is the only possible somatic effect due to exposure to low levels of ionizing radiation. According to the 1990 BEIR Report (ref. 1), the risk of radiation doses of the order of the natural background level (300 millirem average in the US) may be zero. However,
to be conservative, the risk factor derived from high dose data is often used to estimate the upper-limit risk of chronic radiation doses less than 10 rem. Accordingly, the International Commission on Radiological protection (ICRP; ref. 2) estimates that the total fatal risk is about $4 \times 10^{-4}$ per rem of effective dose equivalent (or 4 chances in 10000 per rem) when averaged over an adult population of radiation workers. This is also the somatic risk factor recommended by the US Nuclear Regulatory Commission for radiation workers (ref. 3).

The average effective dose equivalent for our research and laboratory medicine personnel is less than 10 millirem (0.010 rem) per year due to work related activities. This low dose value suggests an average upper limit fatal risk of about one chance in a quarter of a million due to each year's occupational exposure. This is an extremely low annual fatal risk which can be put into perspective by comparing it with other actions that suggest the same fatal risk level, e.g., smoking 14 cigarettes (in a year), driving an automobile 40 miles, drinking 30 cans of diet soda, etc., (ref. 4).

16.3.2 Genetic Effects

A mutation is an inheritable change in the genetic material within chromosomes. Generally speaking, mutations are of two types, dominant and recessive. The effects of dominant mutations usually appear in the first and subsequent generations while the effects of recessive mutations do not appear until a child receives a similarly changed gene for that trait from both parents. This may not occur for many generations or it may never occur. Mutations can cause harmful effects which range from undetectable to fatal. In this section mutational effects mean only those inheritable conditions which are usually severe enough to require medical care at some time in a person's lifetime.

The ICRP (ref. 2) estimates the probability of radiation-induced severe hereditary effects in all descendants of a population of radiation workers to be $6 \times 10^{-5}$ per rem (or about one chance in 17,000 per rem). An UNSCEAR report (ref. 5) estimates that about ¼ of the affected descendants would be children and grandchildren.

This information can be combined with the average annual dose of approximately 10 millirem to estimate the genetic risk of our research and laboratory medicine radiation workers. Assuming 11 years of exposure prior to conception (29 years is the average age of fathers at the time of birth in the US; the average age of the mother is less; 18 years is the minimum age for occupational exposure to ionizing radiation), the chance of a serious birth defect in all descendants of the worker due to prior occupational exposure is less than one chance in a hundred thousand due to prior occupational exposure ($11 \times 0.01 \times 6 \times 10^{-5} \sim 7 \times 10^{-6}$). This risk is very low. Many experts consider the risk to be nonexistent.

However, it should not be surprising for such a small dose. For perspective, the radiation dose due to single roundtrip air flight can be as high as 20 millirem (ref. 6), substantially higher than the average annual dose of our research and laboratory medicine personnel.
16.3.3 Developmental Effects

An exposed unborn child may be subjected to more risk from a given dose of radiation than is either of its parents. The developmental effects of radiation on the embryo and fetus are strongly related to the stage at which exposure occurs. The greatest concerns are of inducing malformations and functional impairments during early development and an increased incidence of cancer during childhood. The most frequent radiation-induced human malformations are small size at birth, stunted postnatal growth, microcephaly (small head size), microencephaly (small brain), certain eye defects, skeletal malformations and cataracts. **Fortunately, these effects are observed only for radiation doses much larger than those permitted radiation workers.**

The current knowledge regarding developmental effects, according to the ICRP, is as follows:

- exposure of the embryo during the first 3 weeks following conception may result in a failure to implant or an undetectable death of the conceptus. Otherwise, the pregnancy continues in normal fashion with no deleterious effects. This "all or nothing" response is thought to occur only for acute doses greater than several rem,

- after 3 weeks, malformations may occur which are radiation dose dependent but with a threshold dose estimated to be about 10 rem of acute exposure,

- from 3 weeks to the end of pregnancy it is possible that radiation exposure can result in an increased chance of childhood cancer with a risk factor of, at most, a few times (probably 2 to 3) that for the whole population, and

- irradiation during the development of the forebrain, in the period of 8–15 weeks after conception, may reduce the child's IQ by 0.3 point per rem, on the average, for relatively large doses.

These conclusions are reassuring for individuals who incur small work–related doses since the possible developmental effects are thought to occur only at much higher doses or to occur with very low probability, if at all.

The US Nuclear Regulatory Commission (NRC) has developed guidance for workers concerning the risks associated with occupational radiation exposure (ref. 3) that is more extensive than this summary. You may request a single copy of the USNRC document (Regulatory Guide 8.29 "Instruction Concerning Risks From Occupational Radiation Exposure") by calling Radiation Safety at 314–362–3476 and asking for a copy of Regulatory Guide 8.29.

References:


6. Radiation Answers – Answers to Questions about Radiation and You (http://www.radiationanswers.org)