

$^{90}\text{Sr} - ^{90}\text{Y}$ biokinetics at incorporation determine the radiation burden to bone marrow*

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The decay characteristics of $^{90}\text{Sr} - ^{90}\text{Y}$ ensure that the mother and daughter nuclides exist in radioactive equilibrium, unless they get discriminated on the basis of their chemical properties, as it happens during metabolism. Although bone is the ultimate organ of deposition, the two nuclides arrive at this target organ over different biokinetic pathways. As $^{90}\text{Y}$ is not excreted, it goes through transient deposition in the liver before being secondarily deposited in bone. This leads to a temporary radioactive excess of $^{90}\text{Y}$ in bone. Since the decay energy of $^{90}\text{Y}$ is by a factor of about 4 higher than that of $^{90}\text{Sr}$, the initial radiation burden to the bone marrow is primarily due to $^{90}\text{Y}$. This was estimated in rats by implanting LiF thermoluminescence dosimeters (TLD) in the marrow cavity of the femur. By calibrating the TLD against a known source of $^{90}\text{Sr} - ^{90}\text{Y}$, the absorbed dose rates and cumulative doses were determined as a function of time after incorporation. Two routes of administration were employed and their influence on the radiation burden is also shown.

In recent years, there has been revived interest on the radiation toxicology of typical long-lived fission products like strontium-90 ($^{90}\text{Sr}$) and its radioactive daughter yttrium-90 ($^{90}\text{Y}$). The nuclear reactor disaster at Chernobyl and the political decline of the former Soviet Union - after which classified information on environmental disasters at nuclear reprocessing plants became known - are responsible for this development. Although the biokinetics of these two radionuclides are different, they ultimately deposit in bone. The radiation burden to the bone marrow is, therefore, of primary interest since haemopoietic cells are far more radiosensitive than the other cells adjacent to the mineral compartments of bone. $^{90}\text{Sr} - ^{90}\text{Y}$ exist in radioactive equilibrium in accordance with physical laws, since the half-life of $^{90}\text{Sr}$ (28 years) is much greater than that of $^{90}\text{Y}$ (64 hr). Separation of the nuclides temporarily upsets the radioactive equilibrium, until it is reacquired. When $^{90}\text{Sr} - ^{90}\text{Y}$ in equilibrium are incorporated into a mammal, the different biokinetics of the nuclides cause them to take different metabolic pathways. $^{90}\text{Y}$ is hardly excreted and is transiently deposited in the liver, from which it secondarily deposits into bone. $^{90}\text{Sr}$ is excreted and also directly deposited in bone following a biokinetic pattern similar to calcium.

The partial excretion of $^{90}\text{Sr}$ coupled with the secondary deposition of $^{90}\text{Y}$ from liver to bone causes a shift in the ratio of radioactivity of the two nuclides to the favour of $^{90}\text{Y}$; i.e. $^{90}\text{Y} : ^{90}\text{Sr} = > 1$. As the decay energy of $^{90}\text{Y}$ is about a factor of 4 greater than that of $^{90}\text{Sr}$, the initial radiation burden to the bone marrow and adjacent tissues is mainly attributable to $^{90}\text{Y}$. This is demonstrated here by direct dosimetry in the marrow cavity of rats by using LiF (lithium fluoride) crystals for thermoluminescence dosimetry. $^{90}\text{Sr} - ^{90}\text{Y}$ was administered via two routes and their influence on the radiation burden is shown. The implications towards human contamination during radiation accidents are discussed.

Materials and Methods

A total of 30 female albino rats at 30 weeks of age were caged in groups of 3 after randomisation. Each rat received 1.0 MBq/kg body weight $^{90}\text{SrCl}_2$ which was in radioactive equilibrium with $^{90}\text{Y}$. The radionuclide mixture was administered to half the animals intravenously, while the remaining cohort received it subcutaneously. On days 1, 2, 4, 8, 16, 32 animals from each cohort were sacrificed, both femora and tibia from each animal were removed, cleaned of adnexa and used for further assay. Using a dentist's drill, the marrow canal at the distal end of each femora was bored open for the insertion of the TLD dosimeter. The femora with the inserted...
dosimeters were kept submersed in water during exposition. The tibia were dried in an oven and used for measuring the activity ratio of $^{90}Y : ^{90}Sr$.

In order to determine the initial radiation burden which is attributable to the initial excess in activity of $^{90}Y$, the dose rates were determined. This was achieved by calibrating the dosimeters against a known $^{90}Sr - ^{90}Y$ source. LiF dosimeters (TLD 100) were obtained from Harshaw, Cleveland, Ohio, USA. The dosimeters were always annealed before use. An integration of the dose rates over time yielded the cumulative doses.

The activity ratios of $^{90}Y : ^{90}Sr$ was not determined by liquid scintillation beta-spectrometry to avoid the inconvenience of dissolving the bones. Instead, the dried bones were directly assayed in a well type liquid scintillation pulse height analyser (ARMAC 3000 from Packard). Since the maximal beta energy of $^{90}Y$ is 2.26 MeV and that of $^{90}Sr$ is 0.54 MeV, the decay energy of $^{90}Y$ is by a factor of 4.18 greater than that of $^{90}Sr$. The Bremsstrahlung of the respective nuclides are of corresponding energy levels, the difference being sufficiently large to permit discrimination between them by appropriate window settings.6

Results

At radioactive equilibrium, the ratio of $^{90}Y : ^{90}Sr$ is one. Incorporation of the nuclides subjects them to different biokinetic pathways. Fig. 1 shows the activity ratios of $^{90}Y$ to $^{90}Sr$ in femora as a function of time after intravenous and subcutaneous injections. The initial kinetics are quite different. Intravenous administration gave $^{90}Y : ^{90}Sr$ ratios of more than one within the first day of incorporation, maximal excess being reached about the fourth day. In comparison, subcutaneous injection gave initial ratios of less than one (about 0.5) on the first day, reaching one around the third day and acquiring maximal value about the eight day. Thereafter, the ratios in both cases receded but did not reach one even on day sixteen.

Figure 2 gives the dose rate (cGy/hr) in the femoral marrow cavity for both forms of administration as a function of time. The discrepancy in the dose rates is clearly in the initial phase, being largest on the first day and approaching comparable values at about day 8. Intravenous injection led to the higher dose rates which is attributed to the higher $^{90}Y : ^{90}Sr$ values during that period. Loss of $^{90}Y$ through decay reduced the ratio and, correspondingly, the dose rates. The consequence expressed in cumulated dose is

![Graph showing activity ratios of 90Y:90Sr](image1)

**Fig. 1**—Kinetics in activity ratios of $^{90}Y : ^{90}Sr$ is shown as a function of time (days) after incorporation of the radionuclides, which were in radioactive equilibrium at the time of incorporation. The route of incorporation influenced the ratios significantly during the first few days. Analyses of variances were done and the error bars indicate the mean variance. The activity ratios were measured in tibia.

![Graph showing dose rates](image2)

**Fig. 2**—Dose rates in cGy/hr in marrow canal of femora were estimated using TLD 100. The influence of the route of incorporation on the dose rates was highly significant during the first few days after incorporation, correlating well with the higher $^{90}Y$ activity during the initial phase. Error bars indicate the mean variance.

![Graph showing cumulative dose](image3)

**Fig. 3**—Influence of the route of incorporation on the radiation burden, indicated as cumulative doses in cGy, is given for the different time points (days) after incorporation. The cumulative doses were calculated from the dose rates.
shown in Fig. 3. For the period of observation i.e. 16 days, the radiation burden in the marrow cavity for intravenous injection was about 158 cGy and for subcutaneous injection about 127 cGy. The difference in total radiation burden was about 20%.

Discussion

The environmental contamination with $^{90}\text{Sr}$ - $^{90}\text{Y}$ resulting from atmospheric nuclear weapon testing has been greatest in the temperate and polar regions of the northern hemisphere. The situation worsened after the Chernobyl nuclear reactor disaster. Although official institutions regard possible health effects due to the additional radiation burden as being negligible, some epidemiological studies do indeed attribute, for instance, low birth-weight and immune deficiency, neonatal mortality and childhood cancers to increases in environmental radiation burdens.

Incorporation of $^{90}\text{Sr}$ - $^{90}\text{Y}$ in a small animal like a rat results in a quasi homogenous irradiation of bone, the marrow and adjacent tissues because of the high decay energies of both nuclides. The situation is different in the case of humans. The radiation burden will not be homogenous because of the sheer difference in dimensions. Both the bone and marrow will receive varying localised radiation burdens. The radiation burden in the marrow canal of the shaft of human long bones will not lead to acute haematological effects since the marrow in the shaft region is haemopoietically inactive. The spatial distribution of $^{90}\text{Sr}$ - $^{90}\text{Y}$ within the organs is thus critical with regard to the radiotoxicological effects. However, the most active sites of mineral deposition and resorption usually correspond with the active sites of haemopoiesis viz. the trabecular regions in bone. Such being the case, the major part of the incorporated nuclides will be deposited in the trabecular bone, and will be responsible for the radiation burden to the active marrow. As $^{90}\text{Y}$ is hardly excreted, being secondarily deposited into bone, the initial radiation burden may be expected to be due to $^{90}\text{Y}$, as the data presented here indicate. A mathematical model for calculating dose has been published, but it does not take the biokinetic peculiarities of the two nuclides into account.

Individual haemopoietic sites may be expected to be uniformly irradiated in contrast to alpha-emitting bone seekers, whereby the exact site of decay of the nuclide and prevailing microgeometry could be critical for the survival of haemopoietic stem cells and, therefore, for the regenerative ability of the haemopoietic system. Furthermore, the cancerogenic potential of bone-seeking radionuclides is well known. The types of cancers most likely to develop may be different for beta and alpha emitters, depending on the target cells of the respective nuclides.

A nuclear accident can be accompanied by other forms of physical injuries like burns and wounds. The contamination of such injured body areas with radionuclides will facilitate incorporation. The kinetics of incorporation and the subsequent biokinetics of the incorporated radionuclides depend on the chemical properties of the nuclides concerned and on the chemical form at exposure. Although the nuclides were as chlorides in this study, the lower radiation burden resulting from the subcutaneous injection must be related to lower mobility of $^{90}\text{Y}$ from the site of injection. Loss of $^{90}\text{Y}$ is partly through decay at the injection site, which consequently must also result in localised irradiation of the site. The data show that the mode of entry can influence the radiation burden to target tissues significantly.

References