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General considerations on radionuclide contamination of animals and animal products for human consumption: proposals for a simple method to detect radiation and the evolution of the absorbed dose (fission products)

Summary: The ways in which milk, meat and other foods can become contaminated with fission products (particularly radioisotopes of iodine, strontium and caesium) are discussed. The difficulty of radiological monitoring in less developed countries is pointed out.

KEYWORDS: Environmental contamination - Food inspection - Radioactivity - Radioisotopes.

INTRODUCTION

As it was once thought that radioactive products entered the organism mainly through respiration or water intake, maximum permissible concentrations (MPC) were initially established for air and water.

In the wake of nuclear tests and nuclear reactor accidents, however, it was revealed that the main components of radioactive fallout were a mixture of fission products (FP) which entered the body almost exclusively through food intake (Sr-90 and Cs-137, for example).

Thus, the main cause for concern in the vicinity of nuclear power plants is not the iodine-131 content in the atmosphere, but rather human contamination from vegetables and secondarily from milk, due to rapid I-131 deposition on vegetation.

Similarly, when water from a river is used to cool nuclear reactors, the principal danger is from fish in the river rather than from the water itself.

Living beings play an essential role here, by virtue of their ability to concentrate radionuclides. Fish and shellfish, for instance, concentrate P-32, Fe-59 and Sr-90.

Special attention should therefore be devoted to the ingestion of fission products:

a) by carrying out preliminary food surveys to assess the eating habits of different populations and their average consumption of various “sensitive” products;

b) by determining average contamination rates for these products after a nuclear incident;

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c) by proposing a simple method for detecting nuclear incidents as rapidly as possible and for evaluating their effects on animals and animal products subjected to radiation;

d) by measuring the dose absorbed after ingestion of fission products, using a “standard” method.

Food and radionuclide absorption

Given the conditions under which contamination occurs, milk is the most important substance in terms of the absorption of the main radioactive elements, in particular those with a short half-life (I-131, Ba-140 and Sr-89).

Milk is also important because it is the sole source of nutrition for infants, who ingest a large quantity every day with respect to their body weight.

Meat has an important role in the daily absorption of caesium, which is physiologically very similar to potassium.

Comparatively, eggs and fish are of minimal importance. In some countries, however, where eggs account for a large portion of human food intake, their role should not be overlooked.

Eating habits

Specific food habits in certain populations should move us to reconsider our conventional Euro-centric approach. (This is one of the problems in establishing international recommendations.)

Thus, in Japan, town-dwellers consume excessively great amounts of fish and other seafood. In this case, Sr-90 may be considered a dangerous radionuclide.

Another example is Lapland, where the main food item is reindeer meat, which contains much more Cs-137 (about 1,110 Bq/kg) than does ordinary beef in other countries (5.5 Bq/kg, approximately).

The amount of Cs-137 absorbed by Laplanders may thus be twenty times higher than the world average.

Fissile matter

Fissile matter (uranium, plutonium, etc.), as well as induced radionuclides (such as Zn-65, Co-60 and Fe-56) are of little importance for land animals; the former are barely absorbed by the gastro-intestinal tract.

We shall see, on the other hand, that the latter are of great importance for aquatic animals.

C-14 deserves special attention, as we can expect its rate to increase in food and in the human body as a result of nuclear accidents.

MILK

The most frequent radionuclides in milk are I-131, Sr-90, Sr-89, Cs-137, Ba-140 and Te-132. There is also P-40 in small quantities; other radionuclides absorbed by cows are not easily metabolised and occur in milk only in very small quantities.
Under normal food conditions, great quantities of I-131 enter the human body through fresh milk immediately after an accident.

Te-132, I-131 and Ba-140 with very short half-lives, and Sr-89 with a half-life of 50.5 days, play only a minor role, whereas at a later stage Cs-137 and Sr-90 must be taken into consideration.

Absorption in herbivores

For herbivores, I-131 is mainly absorbed through ingestion of contaminated fodder and secondarily through air or drinking water.

The storage of fodder naturally eliminates radionuclides with a short half-life (60 days for nearly total elimination of I-131). Washing decreases surface contamination by Sr-90 and Cs-137.

Ewes grazing in a poor pasture will eat stems and the base of plants whereas cows will eat only leaves: ewe’s milk may thus be richer in I-131 and Sr-90 than cow’s milk.

Where doses are continuously administered (I-131 for 7 days), we find 50 to 80% of the daily absorption in the thyroid gland.

Resorption of iodine begins in the rumen. It occurs rapidly and thoroughly in the digestive tract.

A correlation between rainfall and Sr-90 content in milk has also been observed. Dust contributes to direct contamination of plants.

Sr-90 and Sr-89 are absorbed in smaller quantities and only a small fraction is found in milk. Another small fraction is found in muscles, with most of it being located in bones (the mineral element), where it remains many years.

Strontium behaves like calcium, though the latter has a certain discriminative advantage. Thus, by increasing Ca content in fodder it is possible to decrease the amount of Sr absorbed by the digestive tract and thus secreted into milk.

Cows absorb only 5% of ingested Ba-140, which settles on the skeleton like calcium and strontium. Barium’s importance is relatively low.

Cs-137 is well absorbed by the gastro-intestinal tract and tends to settle in muscles and other soft tissue. Its biological half-life in man is 100-140 days, in cows 20 days and in goats 2 to 3 days only.

The metabolism of Cs-137 is similar to that of potassium, although the latter is not predominant, as is the case with calcium/strontium.

Modes of contamination

The secretion of the above radionuclides in milk is linked to the mode of contamination: either a single dose (nuclear accident) or a continuous dose.

In the case of a single dose of I-131, 10% of the dose, at the most, occurs in the thyroid gland about 3 to 5 days after exposure. Within a week, approximately 50% is secreted in urine and 20% in faeces.

In the case of a prolonged dose, the amount of I-131 in milk, urine, faeces and the thyroid gland increases rapidly but reaches a peak after 5 to 10 days.
In fact, I-131 concentration varies greatly in milk. Immediately following an accident, the concentration is generally very high, especially in the immediate vicinity of the reactor. However, this concentration drops relatively quickly (short biological half-life).

After the Windscale accident, a minimum of 1,036 Bq/litre and a maximum of 4,181 Bq/litre were recorded in milk from a single herd.

These variations make it difficult to account for correlations between gamma activity in the ground and I-131 concentration in milk.

Moreover, the correlations change over time. In Europe, values ranging from 3.7 to 22.2 Bq/l due to fallout have been observed. These figures are above "average"; 3.7 Bq/l may be considered the minimum!

It should be noted that the radioactive caesium excretion rate in milk is about 10 times that of strontium. The latter, however, is secreted over a much longer period (longer biological half-life).

The maximum values can be set at 18.5 Bq/l for Sr-89 and at 2.8 Bq/l for Sr-90.

In the United States, the Cs-137 content in milk was generally 2 to 10 times higher than the Sr-90 content. The average can be considered to be 1.85 Bq/l.

In conclusion, daily absorption percentages of a continuous dose per litre of milk are fairly constant for radioactive Sr and Cs. There are, however, great variations as concerns I-131. This must be taken into account in certain circumstances (for example, a reactor accident).

MEAT

The significant radionuclides for food of animal origin settle chiefly in the thyroid gland (I-131), the bones (Sr-90, Sr-89, Ba-140) and in meat (Cs-137).

Caesium gives the most cause for concern in meat for human consumption, though a certain percentage of I-131 and radioactive strontium may also be present.

Where bone or meat powder is used in animal feed, Sr-90 content should be taken into account.

Absorption

Animals exposed to radioactive fallout immediately prior to slaughter should present no danger in terms of food consumption. However, the skin, gastro-intestinal tract and respiratory system should be removed and destroyed.

The I-131 aerosol absorption speed is surprising: 10 minutes after absorption there is notable contamination of the internal organs. Nevertheless, the absorption of I-131 by the digestive tract, although slower, is generally more significant.

Modes of contamination

As with milk, the absorption varies according to whether there is a single dose or a dose spread over time.
Cs-137 has a long radioactive half-life (11,000 days) but its biological half-life is short, and thus its effective half-life as well (as mentioned above, 140 days for man, 20 days for cows and 2 days for goats).

Because of its long radioactive half-life, a “continuous” dose of this radionuclide will bring about greatest absorption.

Although the discrimination factor in the caesium/potassium relationship is not as clear-cut as with strontium/calcium, caesium’s metabolism is not identical to that of potassium.

By raising the potassium content in fodder it is possible to increase appreciably the excretion of potassium and radioactive caesium. This remark is important when considering decontamination.

In meat, 5.92 Bq/kg may be taken as a maximum figure for Cs-137.

**In conclusion**, it can be assumed that the daily absorption of radionuclides dangerous to human health comes from meat: 21% of Cs-137, 3% of Sr-90.

Meat and its by-products rank just after milk and plants as contamination risks for man.

For absorption by cattle, the Cs-137 content in fodder is a prime cause for concern.

In the case of pigs, however, attention should be given to potatoes, cereals, meat-meals, etc.

**OTHER FOODSTUFFS OF ANIMAL ORIGIN**

**Eggs**

Along with milk, fresh eggs are an alarming source of contamination. They may contain not only radionuclides with a long half-life (Sr-90 and Cs-137), but also elements with a short half-life (Sr-89, Ba-140, I-131).

The importance of this fact varies of course with the nutritional habits of the country concerned.

**Fish**

In Europe, for instance, where fish consumption is relatively low, this type of food should not entail a major hazard.

Nonetheless, there is a danger of concentration of activation products in fish and aquatic animals (salt or fresh water).

In the Marshall Islands, 80 to 85% of total radioactivity in sea animals comes from this type of radionuclides (Zn-65, Co-60, Co-57, Co-58, Fe-55, Fe-59, Mn-54).

These radionuclides can also be found in fresh water used for cooling reactors, and thus in the animals living in such water.

Attention should be given to the transfer of radionuclides throughout the salt-water food chain, from phyto-plankton to the most evolved species.
Concerning the latter, in addition to ingestion and transfer via the digestive tract, account must be taken of direct absorption from sea water through the gills.

Here we find dissolved (ionised) strontium, caesium and iodine. Rare earth radionuclides (zirconium, niobium or ruthenium) are linked to volatile substances.

Absorption by plants or animals is greater for elements in solution.

Radioelements linked to volatile matter may be absorbed on the surface in the case of plankton or fish gills.

The persistence of radionuclides with a long half-life in dead animal debris will cause radioactive accumulation in friable sediments.

In fresh water, where salt concentration (calcium and potassium) is very low, we find a higher concentration of strontium and caesium in living beings, as opposed to salt water. Nevertheless, fewer fresh water products are consumed than seafood, and so special attention should be devoted to fish, molluscs and crustaceans.

**THE ROLE OF PROCESSING**

Among the processing methods used for marketed food products, the following should be borne in mind:

For milk, that cheese made from I-131 contaminated milk has rather low radioactivity, mechanically-separated cream contains only 5% of the initial I-131 milk radioactivity, and butter only 0.9%.

Storing milk and dairy products is a decontamination measure for radionuclides with a short half-life (Te-132: 32 days; I-131: 8 days), which are the most dangerous.

In the case of meat, however, which contains mainly radionuclides with a long half-life, storing is not a useful measure.

If meat processing involves dehydration (dried sausage, for example), we can even expect a rise in radioactivity in the final product. This consideration, however, should be coupled with an evaluation of the amount of the product generally consumed by the populations concerned.

Salting should lead to a drop in radioactivity through ion-exchange.

**GENERAL CONCLUSIONS**

Our comments have been intentionally geared towards the risks inherent in radionuclide contamination of animals and animal products.

But does the title “Exposure of animals and animal products to radiation” concern only external contamination?

The technical item requested by OIE Member Countries, and which was prompted basically by the Chernobyl accident, did not appear to be so restrictive.
The topic “exposure to radiation” implies precise knowledge of its effects (immediate and deferred somatic, teratogenic, genetic) and requires complex radiobiological research (interaction between radiation and matter).

The primary interest of OIE Members appears rather to be focused on the consequences of radionuclide absorption by animals and its effects on man (internal contamination) following a nuclear accident.

This is borne out by the reaction to the presentation of Technical Item I. Indeed, nuclear reactor operation can entail radiation dangers due to the radionuclides released in the environment.

The concept of monitoring and surveillance is a matter of concern to some countries which partially or totally lack the technology necessary for such operations. It also concerns the more “developed” countries which perhaps have not yet agreed on the units, definitions, effects (especially for low levels of radiation), etc. Cf. recommendations of the International Commission on Radiological Protection.

We thus need first of all to work out a lexicon, containing the most recent concepts and simple definitions: the maximum acceptable doses on the basis of the type of accident or radiation (global or partial), the type of organ involved, the animal species, etc.

It would be illusory to set such limits without specifying how they are to be monitored and enforced!

International regulations should specify the nature of and responsibility for monitoring (reference laboratories, standards).

Analyses must be comparable. The package of a food product could contain clear indications on this subject. They would be of interest to the consumer, along with the expiry date (or date of production).

**MINIMUM TECHNICAL REQUIREMENTS**

For countries with insufficient technical or personnel resources, simple proposals to meet their legitimate concerns should be advanced.

The following may be proposed.

**Minimum equipment:**
- Gamma-detector with a scintillator.
- A lead cask (to isolate the sample during the natural radioactivity count).

**Preparation of the sample for measurement**

This requires:
- Mineralisation (which anyone can perform). Establish the fresh weight/ash weight ratio.
- Presentation of the sample in fixed geometry.
- Calibration of the installation with a titred solution of a given radionuclide, for a given fixed geometry and equipment.
The results obtained in well-defined conditions will provide an idea of overall radioactivity (first approach) for a given counting period. This measure may, as a detection method, be applied to “sensitive” products such as leaves.

A “variant” consists of transmitting the mineralised sample to a specialised laboratory which will count it and interpret the result (gamma-spectrography for example). Specialised laboratories could use radiation chemistry, beta-counting, etc., on these samples.

RAPID EVALUATION METHOD

Finally, it may be appropriate to propose, in addition, a rapid method to evaluate the absorbed dose resulting from ingestion of food contaminated by fresh fission products.

Such a method requires these preliminary determinations:

- time spent in the contaminated area
- age of mixture of fission products (FP).

Indeed, if the FP are fresh, the mixture is very complex. Another difficulty may stem from a lengthy stay in a contaminated area with respect to the average life of the FP considered.

The critical organs will at first be:

- from day + 1 to day + 30: gastro-intestinal tract and thyroid gland
- after day + 30: bones.

When the FP are relatively old (after 50 days approximately) the decrease in the mixture is insufficiently low to set the daily radioactive rate in relation to the initial rate observed at the beginning of stay in the contaminated area.

This hypothesis enables us to use the notion of MPC and the Summers and Gaske curves for limited time spent in contaminated areas (calculation using these curves to assess the dose in bones).

When the FP are recent, and despite problems in determining the MPC for given FP, the evaluation of doses in the gastro-intestinal tract and the thyroid gland can be effected by a direct reading from the Hamard tables (cf. Atomic Energy Commission).