Strontium

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Abstract

This page draws on 20 peer-reviewed studies. The complete citation list is at the bottom of the page.

1 | Overview

Strontium is an alkaline earth element that the body handles much like calcium, so it is taken up into bone and tooth mineral in place of calcium 1 2. The papers cited here split into two very different bodies of work. A smaller group deals with strontium-90, a radioactive fission product with a physical half-life of about 28.8 years that was released, in small amounts relative to radiocesium, by the Fukushima Daiichi accident 3 4. A larger group uses stable strontium, and especially the ratio of strontium-87 to strontium-86, as a natural tracer of where foods, animals and people come from, because the ratio in plants and skeletal tissue reflects the local geology of the food and water consumed 5 6 7.

For food safety, the practical questions are how much strontium-90 reaches staple foods after a nuclear release, how stable strontium moves from soil into crops, and which foods and waters are strontium-rich. The cited evidence answers the first two in part for Japan and gives scattered measurements for the third. It does not supply a human toxicity assessment for stable strontium.

2 | Toxicology

The cited evidence does not establish a human dose-response relationship or toxicity threshold for stable strontium. The concern raised in the radiostrontium papers is radiological: strontium-90 accumulates in bone and is described as a potential cause of leukemia or bone cancer, a statement those papers make in their introductions rather than test 4 3. For dose assessment, Japanese surveillance work used an adult committed effective dose coefficient of 2.8 x 10^-5 mSv per becquerel of strontium-90 3.

The only direct toxicity data in the cited set are for plants. In spiked farm-soil microcosms, strontium chloride at 5 to 40 mM reduced germination vigor and growth of red fescue and red clover, with pre-germination exposure

most damaging to red fescue; for example, red fescue shoot weight fell from 0.54 mg per plant in controls to 0.21 to 0.30 mg per plant across 5 to 40 mM 8. These doses are far above normal agricultural conditions.

Rodent studies in the set used stable strontium chloride as a stand-in for radiostrontium and focused on absorption, not harm 9 2. In one of them, kidney mineralization appeared in rats fed a 10 percent sodium alginate diet, which the authors attribute to excess sodium rather than to strontium 9.

3 | Typical exposure routes

Food and drinking water are the routes the cited studies describe. Isotope studies across several regions rest on the observation that the strontium in bones and teeth comes from what an animal or person ate and drank while the tissue formed 5 6. Analysis of a single cattle tooth concluded that enamel strontium was wholly diet-derived, whereas lead in the same tooth also reflected release from the animal's own skeleton 10.

Water can matter when its strontium content is high. In controlled rat feeding, Zurich tap water held 0.29 mg/L strontium while a commercial strontium-rich mineral water held 8.6 mg/L, about 30 times more, and rats given the mineral water had measurably different bone and incisor isotope ratios from rats on the same diet with tap water 11. In a marine fish, water supplied about 83 percent of the strontium in the ear stones and food only about 17 percent 12; this reflects fish physiology and cannot be carried over to people.

Salt is a further route. Two archaeological studies of cremated human bone from Belgium and the Netherlands found higher bone strontium in Roman-period groups, especially urban and military groups in the Netherlands, and linked it to salt-preserved and salt-rich foods 13 14.

For strontium-90, the cited route is fallout settling onto soil and vegetation and then entering crops and other foods 4 3.

4 | Food sources

Strontium-90 in foods after Fukushima

Japan's national food surveillance detected strontium-90 in 25 of 40 foods that also carried accident-derived radiocesium and in 8 of 13 that did not, at 0.028 to 0.87 Bq/kg fresh weight and 0.42 to 3.7 Bq/kg dry weight in the radiocesium-positive group 3. Levels in rice, wheat, soybeans, beef, freshwater fish and mushrooms fell within ranges recorded before the accident, so the survey found no clear accident-related increase 3. Bran fractions and dried leaf products carried the higher values, and a whole marbled flounder analyzed with its bones held about twice the strontium-90 of earlier muscle-only sea fish data 3.

STUDY / LOCATION	MATERIAL / DESIGN	METAL SPECIES	VALUE (UNITS AND BASIS)	N	INTERPRETATION / LIMITATION
1 Japan, 2011 to 2013	Brown rice, radiocesium--positive	90Sr	0.036 to 0.071 Bq/kg fresh weight	4 (3 detected)	Within pre-accident range; lowest LOD 0.02 Bq/kg
1 Japan	Rice bran; wheat bran	90Sr	0.27 Bq/kg; 0.57 Bq/kg fresh weight	1 each	Bran fractions higher than whole grain

1 Japan	Crude wheat; soybean	90Sr	0.057 and 0.16 Bq/kg; 0.28 Bq/kg	2; 1	Soybean without accident radiocesium 0.15 Bq/kg
1 Japan	Beef, radiocesium--positive	90Sr	0.028 and 0.081 Bq/kg	5 (2 detected)	Only slightly above LOD
1 Japan	Whole pond smelt and loach	90Sr	0.073 to 0.15 Bq/kg (positive); 0.028 to 0.17 Bq/kg (negative)	4; 3	Bones included; similar with or without accident radiocesium
1 Japan	Dried mulberry leaf tea	90Sr	3.7 Bq/kg (positive); 2.0 to 5.5 Bq/kg (negative), dry weight	1; 3	Highest values; high even without accident radiocesium, consistent with older fallout
1 Japan	Dried shiitake harvested 2010	90Sr	0.88 Bq/kg dry weight	1	Pre-accident sample, shows background fallout
2 eastern Japan, 2011 to 2012	Soil and vegetation at hot spots	90Sr	up to about 1 Bq/g	not stated in text	1 to 4 powers of ten below cesium-137; per-sample data in supplement

Strontium-90 was also detected in green tea (0.60 Bq/kg dry weight) and in wild mushrooms such as kuritake (0.52 Bq/kg) 3.

Stable strontium in crops, feeds, water and salt

A survey of 142 Japanese farm fields found a geometric mean of 78 mg/kg stable strontium in soil (range 12 to 360 mg/kg) and 1.6 mg/kg dry weight in the edible parts of crops (range 0.13 to 88 mg/kg, n = 146) 15. Leafy vegetables had the highest transfer factors and brown rice the lowest: geometric mean transfer factors were 0.27 for spinach, 0.17 for cabbage, 0.048 for tomato, 0.020 for potato, 0.014 for wheat and 0.0032 for brown rice 15. Crop calcium, not soil strontium, best explained how much strontium a crop held 15.

STUDY / LOCATION	MATERIAL / DESIGN	METAL SPECIES	VALUE (UNITS AND BASIS)	N	INTERPRETATION / LIMITATION
3 Japan, 142 fields	Agricultural soil, 0 to 20 cm	stable Sr	GM 78 mg/kg (12 to 360)	142	Background levels; analytical details in a separate report
3 Japan	Edible crop parts, 25 crop types	stable Sr	GM 1.6 mg/kg dry weight (0.13 to 88)	146	Dry basis; several crops with 1 or 2 samples

4 Switzerland and Germany, laboratory	Pelleted animal diets (insect, plant, meat meal)	stable Sr	11.7, 19.6 and 26.4 µg/g	9 aliquots each	Laboratory feeds, not human foods
4 Zurich	Municipal tap water; commercial mineral water	stable Sr	0.29 mg/L; 8.6 mg/L	14; 2	Single city and single product
10 Scotland, microcosm	Red clover shoots, unspiked control; 40 mM spiked	stable Sr	0.036 g/kg; 17.4 g/kg	9; 3	Forage legume; spiked doses far above field levels
6 Belgium (literature values quoted)	Marine and rock salts	stable Sr	10 to 153 ppm	15 salts	Secondary values cited by the authors, not measured in that study

The salt values in the last row, and the authors' citation of up to 4.6 ppm in salted hams against 0.1 to 1.1 ppm in pork, are quoted from earlier studies and should be checked against the primary sources before use 13. They still indicate that salt, and particularly sea salt, can be a notable strontium source. An older paleodiet synthesis describes maize (corn) as a low-strontium food whose adoption lowered bone strontium in prehistoric Ontario 1.

The cited evidence contains no measured stable strontium concentrations in retail foods such as seaweed, milk or fish, and no total diet study.

Strontium isotopes and food origin

Strontium isotope ratios can verify where a food was produced. A New Zealand isotope map predicted the farm origin of 33 cow milk samples with closest predictions averaging 7.05 km from the true location 16. Overlapping isotope signatures between candidate regions can, however, prevent a confident assignment, as a reanalysis of archaeological maize from Chaco Canyon showed 17.

5 | Regulatory limits

The cited evidence states no regulatory limit for stable strontium in food or water.

For radioactive strontium, Japan's standards that took effect on 1 April of 2012 limit radiocesium to 100 Bq/kg in foods other than drinking water, milk and infant foods, and were set so that the dose from the target radionuclides, including strontium-90, would not exceed 1 mSv per year 3. Strontium-90 is not measured directly under this scheme; its contribution was built in through assumed ratios to cesium-137, reflecting an assumption that strontium-90 activity stays at or below 10 percent of cesium-137 4. Field and food data supported that assumption for the samples tested: no soil or vegetation sample exceeded the 10 percent ratio 4, and the highest committed effective dose ratio of strontium-90 to radiocesium in foods was 0.063 against the 0.5 assumed when setting the limit 3. The one exception was whole freshwater fish, whose observed strontium-90 to cesium-137 ratios of 0.0039 to 0.025 exceeded the estimated 0.000024; recalculating with the highest ratio did not change the derived radiocesium limit, because consumption of such fish is low 3.

6 | Testing

Strontium-90 is a pure beta emitter and requires radiochemical separation before counting, which makes it slow and costly to measure compared with gamma-emitting radiocesium 3 4. Japanese food surveillance ashed samples at 600 degrees C, separated strontium by cation exchange or ferric chloride co-precipitation, and counted the yttrium-90 daughter on a low-background gas-flow counter, correcting for chemical recovery (mostly above 75 percent) and validating with IAEA reference materials; the lowest detection limit was 0.02 Bq/kg 3. Soil and vegetation work used a strontium-selective extraction resin and liquid scintillation counting with a strontium-85 recovery tracer (92.4 to 98.2 percent recovery) 4.

Stable strontium concentrations in the cited studies were measured by ICP-MS (limit of quantification 0.05 ppb in mouse bone digests) 2, by ICP-OES in plant tissue, water and skeletal samples 8 11 18, and by graphite furnace atomic absorption spectrometry in binding experiments 9. Isotope ratios were measured by multi-collector ICP-MS or thermal ionization mass spectrometry against the NIST SRM 987 standard 14 6.

One analytical caution applies to laboratories measuring rubidium: strontium-87 overlaps rubidium-87 in ICP-MS, and a reaction-cell method with fluoromethane gas was developed to remove this interference 19.

7 | Microbiome effects

The cited evidence does not establish any effect of strontium on the gut microbiome. The only microbiological use in the set is strontium chloride as a selective ingredient in laboratory enrichment broth for isolating Salmonella, which says nothing about gut exposure 20.

8 | Vulnerable populations

The cited evidence does not identify populations at higher risk from strontium. None of the papers measured strontium-90 or stable strontium intake in children, pregnant women or other groups, and the animal absorption studies were done in young male rodents 9 2.

9 | Mitigation

Two animal studies tested foods and food additives that reduce strontium uptake from the gut. In rats fed diets with 10 percent sodium or calcium alginate for two weeks, plasma strontium fell to 63 to 77 percent of control, and the peak plasma concentration after an oral strontium chloride dose fell from 108 ng/mL in controls to 58 and 37 ng/mL; calcium alginate was judged safer because sodium alginate caused kidney mineralization 9. That paper also reports an IAEA recommendation of 4 g per person per day of sodium alginate for patients exposed to large amounts of radioactive strontium 9. In mice given a single oral strontium dose, kelp, its polysaccharide laminaran, and calcium alginate lowered femur strontium to 92.1, 80.2 and 75.4 percent of control after 24 hours, while a single dose of sodium alginate had no effect 2. Neither study establishes effective human doses.

For soils, red clover moved strontium into its shoots at translocation factors of 2.65 to 25.3, far more than red fescue, and its authors propose it for phytoremediation of contaminated ground 8. The same property means clover grown as forage on contaminated land would carry strontium into feed, a link the study did not test.

The cited evidence does not establish food processing steps that reduce strontium. Higher strontium-90 in rice and wheat bran than in whole grain suggests that the outer layers carry more of it, but no paper measured removal by milling or cooking 3.

10 | Open questions

- No toxicity assessment or reference value for stable strontium in people appears in the cited evidence; Toxicology rests on plant data and background statements.
- No regulatory limit for stable strontium in food, water or supplements is stated in the cited papers.
- No measured stable strontium concentrations in retail foods, total diets or dietary supplements; Food sources relies on Japanese crops, laboratory feeds, two waters and literature values quoted for salt.
- No strontium-90 food data outside Japan, and no intake estimates from measured diets.
- Effects of strontium on the gut microbiome are not addressed.
- Vulnerable populations are not addressed; no data on children, pregnancy or bone-disease groups.
- Whether milling, washing or cooking removes strontium-90 or stable strontium from grains and leaves has not been measured.
- Human efficacy and safe doses of alginate or kelp as strontium-uptake countermeasures are unknown.
- Per-sample strontium-90 values for Fukushima soil and vegetation are only in an unarchived supplement.

11 | What remains uncertain

Most of the 25 cited papers are archaeological or geological studies that use strontium isotope ratios as a tracer. They are strong evidence that skeletal strontium comes from food and water and that isotope ratios can verify geographic origin, but they say little about how much strontium people consume today or whether any intake is harmful.

The food-safety evidence that does exist is concentrated in Japan after Fukushima and in one national soil-to-crop survey. Strontium-90 levels in foods were low and close to pre-accident fallout ranges, many results sat near detection limits, and comparison groups differed in commercial status as well as contamination. Stable strontium crop data are on a dry-weight basis with limited samples for many crops.

Mitigation evidence comes from small rodent studies using large single or dietary doses of stable strontium. Two co-authors of the rat alginate study worked for the company that supplied the alginate, and the mouse study used alginates from the same supplier, so independent replication would strengthen confidence.

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