# Fool Irradiation: A Potential Unwanted Byproduct of Food Irradiation?*

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## Abstract

What is the *rate* of fatal or serious accidents at industrial irradiators? The numerator of this rate is surprisingly high: in the past 30 years there have been at least 8 serious accidents with sterilizers: Norway, 1982 (40 Gy); Israel, 1990 (15 Gy); Italy, 1975 (14 Gy), Peoples Republic of China, 1980 (8.3 and 3.2 Gy); El Salvador, 1989 (5.3 Gy); New Jersey USA 1974 (4.1 Gy); New Jersey USA 1977 (2.1 Gy); and Peoples Republic of China 1987 (1.35 Gy). There have been at least 50 serious accidents involving sealed sources of all kinds. In too many cases, safety procedures were foolishly violated or safety systems intentionally defeated and we have had "fool irradiation." For food irradiation to be acceptable, acute radiation deaths or injuries of food irradiation workers must not be substituted for the rare consumer death attributable to E coli 0157:H7. The recent IAEA review "Lessons Learned from Accidents in Industrial Irradiation Facilities," and the ICRP Publication 76, "Protection from Potential Exposures: Application to Selected Radiation Sources" show the way to prevent future "fool irradiation," thereby making possible the benefits of food irradiation.

## Introduction

There has been a gradual regulatory acceptance of food irradiation, both internationally (World Health Organization 1994) and nationally (Animal and Plant Health Inspection Service 1989, Food and Drug Administration 1985, 1986a, 1986b, 1989, 1990a, 1990b, 1995a, 1995b, 1997, Food Safety and Inspection Service 1992); concurrently, there has been consumer resistance based on the fear that irradiated food is unhealthy and that food irradiation is hazardous to workers (see, for example, http://www.pure-food.com/food.htm , http://www.kilima.com/bill62.html ,or, http://www.nfpa-food.org/Editorial/editNov97.html ). Part of the concern for worker safety is based on isolated incidents in which a few workers have died or been irradiated.

As part of a project for the U.S. Nuclear Regulatory Commission (NRC), researchers at Pacific Northwest National Laboratory (PNNL) began compiling data on accidents with sealed sources (Strom et al. 1994b; Strom et al. 1994a). This database has been incorporated into an ongoing

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project entitled Quantitative Evaluation of Contamination Consequences (QECC) (Strom et al. 1998). More information about QECC is available at http://qecc.pnl.gov.

Data on industrial irradiator accidents were compiled by the U.S. Nuclear Regulatory Commission (Trager 1989) and the IAEA (1996). For other accidents, data have had to be combed from the scientific literature and government reports, including the IAEA (1998). The accident data represent "numerator data" in the sense that we have been unable to locate the number of irradiators in use as a function of time, and the numbers of workers at irradiators. These two kinds of information are needed to compute rates of irradiator accidents in units of accidents per person-irradiator-year. Such rates could be used for trends and projections.

**Measures of the Severity of An Irradiator Accident**

The number of people killed or seriously injured or highly irradiated is, of course, the highest level outcome of an accident. In the case of accidents with sealed irradiator sources, the number of persons involved has usually been one. It is difficult to compare these accidents because of differences in radionuclide, source strength, facility design, and operating procedures. Traditional comparisons are anecdotal and focus on "lessons learned"

We propose a different kind of measure—the time-and-proximity factor—which removes radionuclide and source strength from the description of the person's interaction with the source.

For an unshielded point source, dose equivalent H depends on exposure time t (hours), distance r (meters), source strength A (activity in Ci) and isotope (through Ã in rem/hr $m^2$/Ci or Sv/h $m^2$/Bq):

$$\begin{aligned} H &= \int \dot{H}\, dt \\ &= \int \frac{\tilde{A} A\, dt}{r(t)^2} \\ &= \tilde{A} A \frac{t}{r^2}. \end{aligned} \qquad (1)$$

For each individual exposed in an incident for whom the dose equivalent $H_E$ is known, the source isotope and activity are known, one can calculate a time-and-proximity factor for the incident. This factor is independent of both source strength and radionuclide involved.

The outcome measure *time-and-proximity factor*, $f_{\text{time \& prox}}$, for external irradiation of an individual by a source of activity *A* (Bq) is

$$f_{\text{time\&prox}}\,(\text{h m}^{-2}) = \frac{H_E(\text{Sv}) \times 1\text{h}/3600\text{s}}{\tilde{A}(\text{Sv m}^2\text{s}^{-1}\text{Bq}^{-1})\; A(\text{Bq})} = \frac{10^{12}\, H_E(\text{Sv})}{\tilde{A}^*(\text{mSv m}^2\text{h}^{-1}\text{GBq}^{-1})\; A(\text{Bq})}. \qquad (2)$$

where $\tilde{A}$ is the specific effective dose equivalent rate constant (in SI units) and $\tilde{A}^*$ is the same quantity is common units as tabulated in QECC. For this outcome measure, $H_E$ is the observed dose that an individual received during an incident, and $f_{\text{time \& prox}}$ the number of "hours at a meter from the source" that the individual would have had to spend to receive that $H_E$.

The *collective* time-and-proximity factor, $f_{\text{time \& prox}}$, for external irradiation of $N$ individuals by a source of activity $A$ (Bq) is

$$f_{\text{time\&prox, coll}}\,(\text{h m}^{-2}) = \frac{\sum_{i=1}^{N} H_{E,i}(\text{Sv})\times 1\text{h}/3600\text{s}}{\tilde{A}(\text{Sv m}^2\text{s}^{-1}\text{Bq}^{-1})\ A(\text{Bq})} = \frac{10^{12}\sum_{i=1}^{N} H_{E,i}(\text{Sv})}{\tilde{A}^*(\text{mSv m}^2\text{h}^{-1}\text{GBq}^{-1})\ A(\text{Bq})}. \qquad (3)$$

Individual and collective time-and-proximity factors are useful in risk analyses to determine the probable distribution of individual and collective doses from a specified source in a particular accident or incident scenario.

Distributions of time-and-proximity factors can then be applied to similar accidents to determine external exposures, even those involving a radioactive source of different isotope and activity. One simple definition of $f_{\text{time \& prox}}$ is the number of hours one would have to spend at one meter from the source to receive a dose equivalent of $H_E$.

If the source remained partially or wholly shielded, then an additional factor should be introduced:

$$f_{\text{time\&prox}} = \frac{H_E}{F_s \tilde{A} A} = \frac{t}{F_s r^2}. \qquad (4)$$

where $F_s$ is the fraction transmitted through a shield, a number less than 1. $F_s$ can be taken as the dose rate at 1 m from the source (in its shield) to the unshielded dose rate at 1 m.

When sources are sub-divided, the full activity is still used in the calculations because the human interaction is what we want to characterize, not the immediate source. So doses from the 1983 Mexican accident, for example, are attributable to the entire source.

**Theoretical Limits Are Not Useful**

The theoretical upper limit on $f_{\text{time \& prox}}$ is

$$\frac{1\ \textit{lifetime}}{(\textit{very close})^2}\ , \qquad (5)$$

where (very close) represents a small distance from the source, e.g., 0.01 $m^2$. For a weak source, this represents about $10^9$ to $10^{10}$ hours at one meter, a quantity so large as to be useless.

However, in tens of historical accident cases, a person (too often a child) has found an industrial radiography source and put it in a "hip pocket." In many cases, the "very close" is 1 cm or so, and exposure times have been up to several months. When large sources are involved, such as industrial radiography sources, these cases result in local radiation burns. The ratio of the average bone marrow dose to the dose at the site of the radiation burn is dependent on "how far the bone marrow is away from the hip pocket." In many cases, the bone marrow to burn site dose ratio is over 100, sometimes over 1000. In other words, one needs to look at truly potential exposures which may result in a high dose, but are realistic.

## Summary of Data

Table 1. Summary of Time-and-Proximity Factors from QECC data on 55 sealed source accidents.

| | *Number of* | | | *Time and Proximity Factor (hours at 1 m from source)* | | | |
|---|---|---|---|---|---|---|---|
| ***Type of Accident*** | ***Accidents*** | ***People*** | ***Dead*** | ***Average*** | ***SD*** | ***Geometric Mean*** | ***GSD*** |
| Gamma Gauge | 2 | 4 | | 380 | 230 | 340 | 1.65 |
| Radiography | 26 | 120 | 16 | 106 | 398 | 2.3 | 40 |
| Irradiator | 13 | 16 | 4 | 0.13 | 0.31 | 0.015 | 9.0 |
| Irradiator, low intensity[a] | 2 | 20 | 2 | 69 | 150 | 2.4 | 35 |
| Brachytherapy (many[b]) | 1 | 85 | | 7.1 | 52 | 0.16 | 28 |
| Brachytherapy (few[c]) | 1 | 1 | | 5.0 | | | |
| Teletherapy (many[b]) | 3 | 4832 | 4 | 0.007 | .06 | 8.E-5 | 21 |
| Teletherapy (few[c]) | 5 | 25 | | 1.75 | 7.1 | 0.039 | 65 |
| Pharmaceutical | 1 | 16 | | 0.023 | 0.01 | 0.021 | 1.5 |
| Fuel Reprocessing | 1 | 1 | | 0.054 | | | |
| Total: | 55 | 5121 | 26 | | | | |

[a] The $^{60}Co$ sources in these two facilities had decayed to < 3.7E+11 Bq (< 10 Ci) at the time of the accident.
[b] > 30 people involved in accident; [c] <= 30 people involved in accident

A current search of the QECC database yields 55 accidents with sealed sources, involving 5121 individual time-and-proximity factors in QECC (Table 1). The QECC classification, “Irradiator” combines medical instrument sterilization facilities with food irradiation facilities. The average time and proximity factor for the irradiator category was 0.13, and that for the 4 out of 13 irradiator accidents resulting in fatalities was 0.02.

## Summary

Study of past accidents can help predict future rates of accidents with industrial irradiators *if there is no improvement in radiation protection!* Food irradiation will be unacceptable to the public if serious irradiation accidents continue to occur at a relatively high rate. Following the recommendations of the ICRP (1997) would ensure adequate levels of safety, and would have prevented most of the severe radiation accidents.

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