Zinc-65 in Reactor Workers

Abstract. Zinc-65, hitherto found in cyclotron workers and in other specialized populations, has now been detected in a group of reactor workers. While the highest levels detected are less than 0.2 percent of the maximum permissible concentration, the movement of this neutron-induced radionuclide is of interest, and the baseline information is important for future studies.

To date, body burdens of zinc-65 have been detected in the members of three populations: the Marshallese exposed to nuclear fallout resulting from the 1 March, 1954 detonation (*1–3*); a group of individuals who drank water from the Columbia River below the Hanford Atomic Works, or who ate food grown in fields irrigated by this same water (*4*); and particular groups of cyclotron workers (*5, 6*). The present study reports a fourth population with detectable levels of Zn^{65}, a group of specialized reactor workers.

Whole-body gamma counts of seven Marshallese inhabitants, performed at Argonne National Laboratory in 1957, revealed for the first time the presence of Zn^{65} in human beings (*1*). In 1958 and 1959, after the exposed Marshallese had returned to their island, body burdens of gamma emitters of 200 people were measured with a portable whole-body counter (*2, 3*). The mean level of Zn^{65} in male, adult Marshallese in 1959 was 9.4 mμc/kg of body weight, while the mean value of Cs^{137} was 11 mμc/kg, or about 100 times that of an inhabitant of the United States (*3*). The Zn^{65} in the Marshallese derives from local seafood which is consumed (*7*). It was found in 1955 that fish and various mollusks have a marked ability to concentrate this element, as well as other radionuclides (*7*). Zinc-65, a neutron-activated product, was formed as a result of the action of slow neutrons released by nuclear fission on materials associated with weapon testing.

More recently, widespread distribution of Zn^{65} resulting from stratospheric fallout has been detected in a wide variety of foods in this country, although at levels lower than those observed in either the Marshall Islands or the Hanford area. Zinc-65 levels of 178 $\mu\mu$c/kg were detected in Chesapeake Bay oysters and levels of 40 $\mu\mu$c/kg in clams from the east coast (*8*). Zinc-65 at levels of from 30 to 50 $\mu\mu$c/kg has been detected in muscle and liver of Nevada cattle, and in commercial hamburger, beef liver, and milk from the Southwest (*9*). It might therefore be reasonably expected that a Zn^{65} body burden would be detectable in the general population.

Zinc-65 was recently detected in certain cyclotron workers (*5*). This radioactive zinc was produced by neutron radiation of construction material by the reaction $Cu^{65}(d,2n)Zn^{65}$. Similarly, body burdens of Zn^{65} were reported in two cyclotron workers at Massachusetts Institute of Technology (*6*). Van Dilla (*5*) predicted that Zn^{65} would also be found in reactor workers. A study of the gamma spectra of reactor workers, then underway at Brookhaven National Laboratory, already confirmed this prediction.

The gamma spectra of 128 male Brookhaven personnel were obtained in the Brookhaven whole-body gamma spectrometer (*10*). The counter is built around an 8 by 4 in. NaI (T1) crystal detector mounted in a room with 6-in. steel walls. The apparatus utilizes a 100-channel pulse-height analyzer.

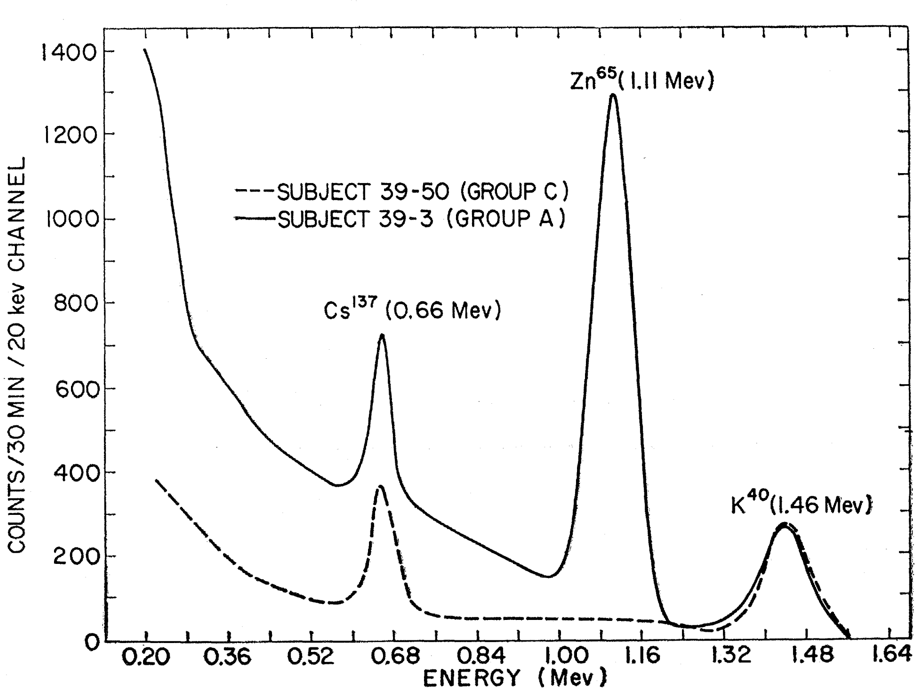

Fig. 1. Gamma-ray spectra of two reactor workers measured in whole-body spectrometer.

Table 1. Primary gamma emitters in reactor workers and other laboratory personnel. Standard deviation $=[\Sigma(x^2)/N]^{\frac{1}{2}}$.

Group	Subject (No.)	K (g/kg body wt)	Zn^{65} ($\mu\mu$c/kg body wt)	Cs^{137} ($\mu\mu$c/g K)
Reactor personnel				
A	5	2.04 ±0.28	1136 ±60.3	65.5 ±22.8
B	21	2.15 ±0.28	64.6 ±34.4	71.1 ±19.2
C	29	1.89 ±0.23	15.7 ±15.2	56.3 ±15.8
Nonreactor laboratory personnel				
D	73	1.84 ±0.25	9.31 ±9.24	59.2 ±16.2

The subjects were showered, dressed in hospital clothes, and placed on a cot in a standardized position under the detector and counted for 30 minutes. The precision of the counter (standard deviation/calibration factor) for a 30-minute count was 12.9 $\mu\mu$c/kg of body weight for Zn^{65}, 3 $\mu\mu$c/g of potassium for Cs^{137}, and 4 g for potassium. Both Cs^{137} and K^{40} can be measured to a precision of 5 percent or greater in a normal 70-kg man with a 30-minute counting time.

Typical gamma spectra from two subjects selected from groups with the highest and lowest Zn^{65} body burdens are shown in Fig. 1. The radionuclide abundances were obtained from the pulse-height data for the discrete energies of the gamma rays Cs^{137}, Zn^{65}, and K^{40}. Corrections were made for the background activity and for the Compton contribution of each radionuclide to the photopeaks of the others. Absolute levels of these three radionuclides were obtained by comparison with the spectra of standardized solutions (KCl to provide K^{40}) placed in a plastic phantom of a standard man (REMAB, Alderson). In addition, 1 μc of each isotope, Zn^{65}, Cs^{137}, and K^{42} (substituting for K^{40}), was administered as the chloride to two patients to check their respective spectra with those obtained from the plastic phantom.

Personnel employed in the Brookhaven Research Reactor were arbitrarily subdivided into three groups on the basis of the degree of their potential exposure to radioactive materials. Group A consisted of workers who handle isotopes which are moved in and out of the pile by pneumatic tubes for irradiation. The mean Zn^{65} level of this group was considerably higher than any other group (Table 1). The Zn^{65} in these workers presumably derives primarily from the reaction, $Zn^{64}(n,\gamma)Zn^{65}$. Zinc is present in external brass fittings of the pneumatic tube system of the reactor. Probably the zinc is carried into the reactor, irradiated, and, on removal, inhaled by the reactor workers.

Group B was composed primarily of pile operators and other personnel such as health physicists who work on or near the reactor. These people were selected on the basis of having higher than normal levels of activity in their urine. Over 66 percent of the individuals in this group had Zn^{65} body burdens in the range of 40 to 120 $\mu\mu c/kg$ of body weight.

Group C was composed of personnel working in the reactor building but presumably having minimal occupational exposure and no detectable level of activity in the urine above background.

Group D was composed of individuals who represent part of a continuing survey of Brookhaven personnel and serves here as a control group against which the spectral data of the reactor workers can be compared. The Zn^{65} levels in groups C and D are below the limit of detection of the whole-body counting apparatus for a 30-minute count.

In addition to the Zn^{65} activity, Cs^{137} and K^{40} were measured in all subjects. The K^{40} content averaged 1.84 g/kg of body weight. This figure agrees well with K^{40} measurements in other similar studies (*11–13*).

The level of Cs^{137} has had a world-wide increase since 1955 and appears to have reached a maximum value in 1959 in the world population (*11–14*). In the present study, the average was 59 $\mu\mu c/g$ of potassium in nonreactor personnel (June 1960) as compared to 52 $\mu\mu c/g$ of potassium at the same time in England (*14*). The Cs^{137} body burden has its origin in world-wide fallout and is associated with ingestion of fallout-contaminated food, particularly milk (*11, 14*). A correlation was found in the present study between the amount of milk consumed by an individual and his Cs^{137}/K ratio.

The interest in Zn^{65} is not based on the radiation hazard that may result from its internal deposition, as even the highest levels detected in the reactor workers of group A were less than 0.1 μc, which is far below the maximum permissible concentration of 60 μc stated by The International Commission on Radiation Protection. Rather, the course of this isotope is interesting because it reveals how a radionuclide—in this case not a fission product, but an induced activity — moves through the food chain or through the atmosphere ultimately to deposit in man. It is of importance to establish baselines for unexposed populations for Zn^{65} and other radionuclides to provide data against which possible increases in body burdens may be measured. Fortunately, the current availability of whole-body gamma spectrometers makes feasible such general population studies. It is, of course, equally important in future studies to keep occupationally exposed personnel in nuclear energy establishments under close surveillance (*15*).

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References and Notes

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15. This work was performed under the auspices of the U.S. Atomic Energy Commission.

19 December 1960

National Academy of Sciences

Abstracts of Papers Presented at the Annual Meeting, 24–26 April 1961, Washington, D.C.

Dielectric Constants and Molecular Interactions in Carbon Dioxide and Ethylene

Measurements at pressures from 1 to 100 atm have been made with sufficient precision to determine density dependent effects attributable to pair interactions of molecules in the two gases. For CO_2, the data show larger dielectric constant increases at 50°C than at 75°C and are satisfactorily explained by the induced polarization effect of a molecular quadrupole moment of about 5×10^{-26} esu cm^2, a figure in reasonably good agreement with other estimates. For ethylene, relatively large increases are also observed, but they increase with temperature in the range 25° to 75°C. This behavior is contrary to theories of quadrupole-induced dipole interactions, even when generalized to molecules lacking axial symmetry. These theories, however, either neglect quadrupole coupling energy or assume that it is small compared with kT. Calculations indicating that the effects of this energy are significant will be discussed, as will experiments which should further clarify the significant interactions between nonpolar molecules.

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Linear Stark Effect in Magnetic Resonance Spectra

If a nucleus or paramagnetic ion with spin greater than one-half occupies a site in a crystal lattice without inversion symmetry, an externally applied electric field will cause, in general, a change in the quadrupole coupling constant or crystalline field splitting proportional to E.

The effect of deformation of the unit cell is additive to the explicit Stark effect at constant strain. The phenomenological description can be given in terms of tensors of third and fourth rank, which are similar to those used by Pockels for the description of the electro-optic and elasto-optic effects in crystals.

An individual ion or nucleus may occupy a site without inversion symmetry, even though the crystal as a whole has such symmetry and is not piezoelectric.

The magnitude of the linear Stark effect in ionic crystals can be readily estimated on the basis of the point charge model. The change in crystal field gradients due to relative displacement of the ions in an applied electric field should, for example, be observable for the nuclear quadrupole resonance of Cl^{35} in $KClO_3$ and for the electron spin resonance of Cr^{+++} ion sit-