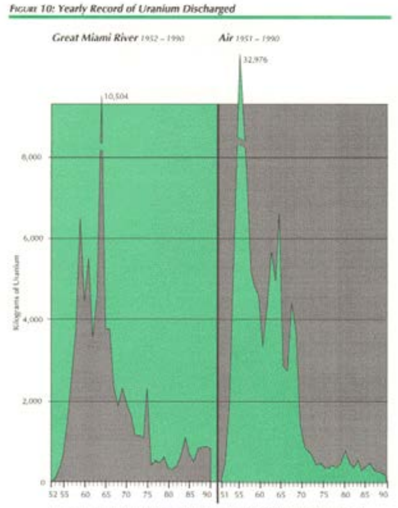
FERNALD DOSIMETRY RECONSTRUCTION STUDY

The Fernald plant was part of the US Department of Energy (DOE) nuclear weapons complex and produced uranium metal products including nuclear reactor fuel elements during operation from 1952-1989. Releases from the site resulted in exposure to ionizing radiation, especially radon, soluble and insoluble forms of uranium, and various other organic and inorganic chemicals. Because there was uncertainty about the quantity of environmental radioactive emissions from the plant to the community, in 1990 the Centers for Disease Control (CDC) contracted with Radiological Assessments Corporation to perform dosimetry reconstruction – an assessment of radiation and uranium doses to members of the public who had lived near the Feed Materials Production Center at Fernald, Ohio (Killough, 1998). The scientists of this project conducted a historical exposure characterization and developed dose estimation models, with an endpoint of developing an algorithm to estimate doses to individual persons who lived within the exposure assessment domain (area within a ten kilometer radius from the perimeter of the plant property). Investigators researched historical records of plant emissions, meteorological data, modeling of the dispersion and deposition of uranium-containing particulate matter, simulation studies, and comparison with results of exposure assessments performed at currently operating radiation-producing facilities.

FIGURE 10: Yearly Record of Uranium Discharged



These graphs show the amount of uranium discharged to the Great Miami River and the air, respectively, throughout the years of FMPC operation. Total yearly data such as these eventually came to be commonplace in later Annual Environmental Reports.

After conducting extensive research to estimate the source term, they reported that from 1952--1989, median estimates of 470,000 kilograms of uranium dust and 160,000 curies of radon-222 were released into the atmosphere, and 90,000 kilograms of uranium were released into surface water (Voilleque, 1995; Meyer, 1996). Most airborne releases of uranium dust occurred prior to 1973, and were in the form of uranium trioxide and uranium tetra- and hexafluoride. Radon emissions from radioactive waste storage silos continued until the vents of the domes covering the silos were sealed in 1979 (Voilleque, 1995; Meyer, 1996, Till, 2000). Ionizing radiation exposure estimates, for each calendar, for each one-kilometer sector of the exposure assessment domain, were calculated using these release amounts.

Environmental radiation exposure to the population living in the Fernald exposure domain, beyond background levels, was estimated by CDC from the exposure algorithms developed as part of the dosimetry reconstruction project. Although CDC did not calculate radiation doses for individual members of the area population, they used the algorithm to calculate estimates for nine hypothetical scenarios.

Cumulative lifetime effective (whole body) radiation dose equivalents for these nine scenarios were calculated by models developed to incorporate the source terms and transport pathways including factors such as particle size and deposition, prevalent wind direction, ground to air resuspension, flow parameters in surface and groundwater, and irrigation of crops. Personal exposure estimates for the scenarios considered residence location, school and work locations, drinking water source, consumption of locally produced meat, fruits and vegetables, consumption of fish from local rivers, and swimming in a local river (Till, 2000). The scenario with the most radiation exposure was a female who lived 1.7 km northeast (generally upwind) of the center of the plant site for 42 years, or during the entire period of the plant operation, but did not drink from a contaminated well. Her median dose estimate, as a cumulative lifetime effective (whole body) dose equivalent, was 61 mSv (which did not include radon progeny). The dose to the lung, attributable to radon progeny, was 3.6 Sv. Two other scenarios, each living 4 km from the site center or two miles from the site perimeter, had lifetime estimates of 9.3 mSv (Scenario 4) and 1.0 mSv (Scenario 8). The higher estimate resulted from living in the area during the early years of plant operation, when emissions from the plant to air and water were greater. For Scenarios 7 and 8, doses to the lung, attributable to radon progeny, were 220 mSv and 380 mSv. Usually, with a threshold model, 200 mSv is considered the minimum lifetime exposure beyond background necessary to increase risk of cancer incidence and mortality (Heidenreich, 1997). The estimates for the CDC scenarios, except for dose to the lung, were considerably below that level.

Figure 48. Cumulative radon dose (Sv) from the K-65 silo releases as a function of an exposed individual's dwelling location. The dose contour curves are based on the subject of scenario 1, who was exposed to the releases for 38 years. She was born in 1946, attended Elda Elementary School, Hamilton-Cleaves Middle School, and Ross High School in the 1950s and early 1960s. Otherwise, she spent most of her time at home. Her home was on Route 126, just northeast of the FMPC site, and the deterministic estimate of her cumulative radon dose for 38 years was 3.0 Sv (Appendix K). The contour plot allows us to see how this cumulative dose would have varied by moving her home about the region, but leaving fixed all other assumptions (including the locations of the schools she attended). For example, her cumulative dose would have remained the same if her home had been located anywhere along the 3.0-Sv contour line. The information in this plot is not applicable to workers at the FMPC site because occupancy times and other assumptions would be different.

<u>Individual uranium exposure estimation:</u>

Individual airborne uranium particulate exposure estimates have been calculated by the Fernald Community Cohort scientists, using the algorithm developed by CDC. For purposes of FCC exposure assessment, we refer to the five-mile radius eligibility area as the FMMP exposure domain. The FCC (FMMP) exposure domain was divided into 100 segments, each approximately one square mile. By applying the exposure estimation methods developed by CDC to our cohort, we calculated, for each year of plant operation, the average concentration of airborne uranium for each segment in the FCC exposure domain, based on the source term, particle size, dispersion and deposition, and distance and direction from the plant.

A participant's estimated exposure for each year was then calculated using the location, calendar year and duration of each place of residence. Addresses within the five-mile exposure domain and dates of residency were obtained from questionnaire data. The locations were then linked to one of the segments within the FCC exposure domain.

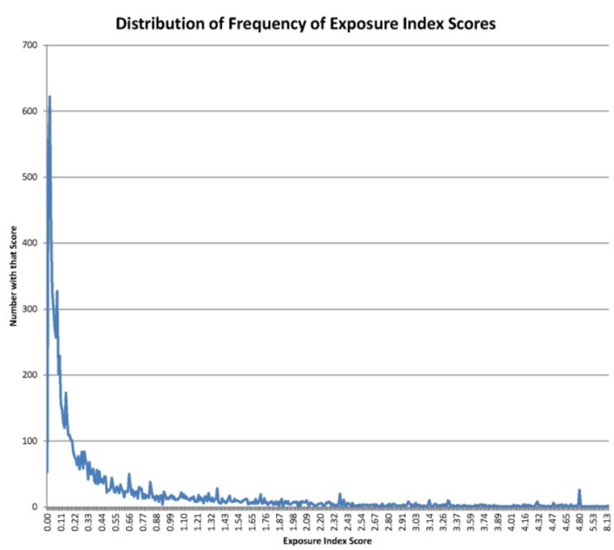
- For each year (or part of a year), the participant's level of exposure to airborne uranium could therefore be determined. For example, a woman living 3 miles northwest of the plant in 1963 would be exposed to an average air concentration of 0.031 µg of uranium per cubic meter of air (µg/m^3). If the same woman were still living there in 1964, she would be exposed to an average air concentration of 0.021 µg/m^3, with the difference reflecting a reduction in plant emissions from 1963 to 1964 and change in the prevalent wind direction.
- The yearly (or partial year) estimates of exposure were summed over all years to calculate cumulative exposure for each participant. For the participant in the example above, assuming she lived there only during the years 1963-1964, her exposure estimate would be 0.052 µg/m^3 - years (i.e., 0.031 µg/m^3 + 0.021 µg/m^3). This cumulative estimate reflected the cumulative amount of airborne uranium, resulting from FMPC emissions during the period of plant operations, to which a participant was exposed.

<u>Constructing dose groups for epidemiology studies</u>

In studies of health effects, uranium exposure was tested as both the cumulative exposure (µg/m^3 –years) and in three exposure levels (non-exposed, very low exposure, exposed). Since the distribution of the cumulative exposure was non-normal, log-transformed values were used in regression analyses. We used the radiation dose estimates for the nine CDC scenarios to assist us in establishing our cut points of the uranium exposure estimates for the three exposure groups. The exposure range for the non-exposed (group 1) was 0.00 - 0.25 ug/m^3 –years. The upper bound of the range was roughly equivalent to the external uranium particulate exposure of CDC Scenario 8, who lived 2.5 miles northeast of the site during the latter years of plant operation, 1975-1989 (Killough, 1998b). Using this scenario provided by CDC, we calculated the exposure estimate for this person to be 0.22 ug/m^3 –years. Scenario 8's cumulative lifetime effective (whole body) dose equivalent (excluding radon progeny) was 1.0 mSv (Killough, 1998b). The upper bound of the exposure estimate range for the low-exposed (group 2) was 0.50 ug/m^3 –years, similar to Scenario 7 (calculated to be 0.66 ug/m^3 –years) with a cumulative lifetime whole body dose equivalent of 5,5 mSv (Killough, 1998b). Scenario 7 lived 6.2 miles south of the site for 38 years, but did not drink contaminated water. For the exposed group, the highest cumulative exposure estimate value was 8.14 ug/ m^3 –years**,** similar to our calculated value for Scenario 1 (lived 1.0 mile northeast of the center of the site for the entire duration of plant operation, 8.59 ug/m^3 –years). The CDC estimate for the cumulative lifetime effective nominal dose equivalent for this person was 61 mSv.

<u>Exposure Profile of the FMMP Population</u>

Much of the cohort never received exposure beyond the background exposure received by the general population. Although the FMMP was established to monitor individuals for health effects of ionizing radiation, findings of dose reconstruction conducted by the Center for Disease Control indicated that a large proportion of those in the screening program received environmental uranium exposure that was negligible compared to background exposure (Killough, 1998a: Killough, 1998b). Extensive uranium dose reconstruction using methods developed by the CDC have demonstrated that over 60% of the FMMP participants had such minimal exposure to uranium and radon that their cumulative ionizing radiation exposure was less than 3.2% over lifetime background levels. For the US population, background ionizing radiation exposure is estimated to be 3.6 mSv per year or 288 mSv lifetime (80 years), but the range of individual exposure estimates is wide (1-10 mSv per year), depending primarily on geographic location (NCR, 1987). The maximum estimate of yearly exposure beyond background for this 60% FMMP sub-cohort is only 5.5 mSv, small compared to the variation in yearly background exposure. <u>Lifetime</u> cumulative exposure from the FMPC for this unexposed sub-group ranges from 0.0 to <0.25 Sv. For the exposed sub-cohort (other 40%), cumulative <u>lifetime</u> exposure from FMPC ranges (approximately) from 250 mSv (0.25 Sv) to over 3660 mSv (3.66 Sv).



The exposure estimates calculated by the University of Cincinnati investigators do not consider the internal uranium dose due to ingestion, especially if a person was drinking uranium contaminated water from a well or cistern. Although the CDC methods do include calculations of organ specific radiation doses incorporating include ingestion of water from contaminated wells and foods, associated uranium doses from these sources have not been calculated by us. CDC also never developed a method for estimating internal uranium dose resulting from ingesting water from a contaminated cistern (collecting rainwater from the roof top). For those who drank from a contaminated well, up to 50% of the total effective radiation dose equivalent was attributable to drinking contaminated water (Killough, 1998b). Of all those in the FMMP cohort, 49% used a well and 31% used a cistern for a primary drinking water source when living at least one residence in the exposure domain (although not necessarily a contaminated well or cistern). Adding these exposure sources to the personal exposure estimates will result in uni-directional increased exposure for some individuals, primarily those in the exposed group.

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