NCRP REPORT No. 95

# Radiation Exposure of the U.S. Population from Consumer Products and Miscellaneous Sources

## Recommendations of the NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS

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these people would receive lung dose-equivalent rates in the range of 0.02 to 0.4 μSv/y (2 to 40 μrem/y). Again, if the assumption is made that the electric power needs are met through the operation of a larger number of plants of smaller capacity, the number of people exposed would probably be larger, but their lung dose-equivalent rates would probably be correspondingly reduced. In either case, however, the dose-equivalent rates are so low as to make the contribution from this source of little significance in the assessment of the total population dose from consumer products.

**3.2.6.3** *Combustion of Natural Gas.* Natural gas contains on the order of 370 to 740 mBq/l (10 to 20 pCi/l) of radon. This amount contributes less than 370 TBq/y ($10^4$ Ci/y) to the worldwide inventory, estimated to be 1.5 EBq (40 MCi) (NCRP, 1975). The dose equivalent to the lungs of people using natural gas in cooking ranges in the home has been calculated by Barton *et al.* (1973) and appears to be about two percent of the normal natural background dose equivalent from radon and its decay products. On that basis, the resulting effective dose equivalent rates to people in homes using natural gas for cooking would be about 20 μSv/y (2 mrem/y) to the alveolar region and 90 μSv/y (9 mrem/y) to the segmental bronchial region of the lung. This latter estimate agrees well with the 60 μSv/y (6 mrem/y) value reported by Johnson *et al.* (1973). According to the American Gas Association (AGA, 1974), the number of residential households using natural gas is about 41 million. If there are, on an average, 3.1 persons per household, the total number of people exposed to radon from the combustion of natural gas in ranges within homes in the United States is estimated to be about 125 million. The average annual bronchial epithelial dose equivalent to those people who are exposed would be about 50 μSv (5 mrem). Using a weighting factor of 0.08,[4] the annual average effective dose equivalent to these people would be about 4 μSv (0.4 mrem) and the associated collective effective annual dose equivalent would be about 500 person-Sv (50,000 person-rem).

In addition, it is estimated that about 16 million people are exposed to radon as a result of the combustion of natural gas in unvented heaters in homes. The dose-equivalent rate to the bronchial epithelium for these people is estimated to be about 0.22 mSv/y (22 mrem/y) (Johnson *et al.*, 1973; Gesell, 1974). Again, using a weighting factor of 0.08, the annual average effective dose equivalent to these people would be about 18 μSv (1.8 mrem) and the associated collective effective annual dose equivalent to the U.S. population would be about 290 person-Sv (29,000 person-rem).

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[4] See Section 3.2.1.

Moghissi *et al.* (1978) have summarized data on collective doses resulting from the use of natural gas. These estimates were based on state-by-state data provided by Johnson *et al.* (1973). Estimates of the annual doses to the tracheobronchial section of the lung were 8,500 organ-Sv (850,000 organ-rem) due to the operation of unvented space heaters and 18,000 organ-Sv (1,800,000 organ-rem) due to the operation of gas ranges. The estimated associated annual effective dose equivalent for people exposed to space heaters was about 50 μSv (5 mrem); the estimate for people exposed to gas ranges was about 10 μSv (1 mrem). The $^{222}$Rn concentrations assumed in the natural gas were 5,550 mBq/l (150 pCi/l) for California, 3,700 mBq/l (100 pCi/l) for Texas, 1,850 mBq/l (50 pCi/l) for another 5 states, and 370 mBq/l (10 pCi/l) for all other states.

A similar analysis of the use of liquefied petroleum gas (LPG) yields annual collective doses to the tracheobronchial section of the lung of 105 organ-Sv (10,500 organ-rem) from unvented heaters, and 185 organ-Sv (18,500 organ-rem) from ranges (Gesell *et al.*, 1977). These estimates are based on an assumed 713,000 dwellings with unvented LPG heaters and 5.3 million dwellings with LPG ranges.

### 3.2.7 *Glass and Ceramics*

Naturally occurring radioactive materials have been used in the glass and ceramic industry for over 150 years (Jensen, 1952). Uranium compounds have been employed to produce fluorescent glassware, a variety of colored glazes, and wall tiles. More recently uranium has been incorporated into artificial teeth both for coloring and fluorescent properties. Thorium compounds have been used in wall tiles and electrical materials.

**3.2.7.1** *Uranium in Glassware.* Sodium uranyl carbonate has been commonly employed in the production of fluorescent and iridescent glass. In particular, it was popular until the 1940's to use this material to produce dichroic properties in glass. As the concentration of uranium is increased, the glass becomes more opaque. In 1972 two manufacturers were identified as using uranium as a colorant in non-food glass products such as candlesticks and flower containers. Federal regulations allow glassware to contain up to ten percent by weight uranium or thorium, except in commercially manufactured glass brick, pane glass, ceramic tile, or other glass or ceramic used in construction. Uranium or thorium concentrations in these latter items are limited to 0.05 percent (CFR, 1986c).

**3.2.7.2** *Uranium in Glazes.* Uranium in the form of oxides and as sodium uranite has been used to produce glazes of black, brown, green, and the spectrum from yellow to red. The glazes were frequently used to decorate tableware and pottery at concentrations ranging from one to twenty percent by weight. As with glassware, the restrictions on the availability of uranium during the 1940's forced manufacturers to find other coloring agents. Since the substitutes were frequently more economical, uranium has not often been used in glazes in recent years. At present no manufacturer is known to use uranium as a glaze for dinnerware. U.S. Nuclear Regulatory Commission (USNRC) exemption limits are set at a maximum of 20 percent by weight (of the glaze) for uranium compounds in glazed ceramic tableware (CFR, 1986c). The acceptability of ceramic glazes for use in food containers is subject to the food additive provisions of the Food and Drug Administration and the use of such glazes is prohibited unless specifically approved. No approvals for such applications of uranium ceramic glazes have been granted to date.

Measurements using film badges have shown that surface dose rates due to gross beta and gamma radiation from various tableware items glazed with uranium range from 5 to 200 $\mu$Gy/h (0.5 to 20 mrad/h) (Menczer, 1965). Measured uranium enamel surface dose rates of 37 $\mu$Gy/h (3.7 mrad/h) have been reported (USNRC, 1983). In addition to the external exposures, uranium and lead have been found on occasion to be leachable from glazed ceramics at levels of 10 to 55 ppm (concentration in the leach solution) (Kendig and Schmidt, 1972). The latter is equivalent to 630 mBq/ml (17 pCi/ml) which is in excess of the Maximum Permissible Concentration in drinking water for occupational exposures, 220 mBq/ml (6 pCi/ml) (NCRP, 1959). At the measured concentrations, the chemical toxicity of uranium is considered to be a greater hazard than its associated radiation. As a result of these measurements, the only known producer of uranium glazes for use in foodware in the U.S. has ceased operations.

**3.2.7.3** *Uranium in Glass Enamel.* Uranium has also been used as a coloring agent in various enamel objects, including tableware and jewelry. Problems associated with the use of such items were highlighted by reports in the early 1980's of relatively high exposures associated with the use of cloisonne jewelry. A surface dose rate of 37 $\mu$Gy/h (3.7 mrad/h) from similar sources has been reported by staff members of the U.S. Nuclear Regulatory Commission (USNRC, 1983). Such jewelry, most of which was being imported, has proven very popular in the U.S. and could be worn in direct contact with the body. Stimulated by these problems, the U.S. Nuclear Regulatory Commission in 1983 banned the use of uranium in enamel products to be sold in the U.S. (USNRC, 1983, 1984). Products already distributed to retail outlets and consumers were not recalled because of logistical problems and the relatively low estimates of the associated radiological hazard.

**3.2.7.4** *Dental Products.* Porcelain teeth and crowns are composed principally of feldspar minerals that contain small quantities (0.001 percent) of naturally occurring $^{40}$K. The practice of adding uranium salts was initiated at least half a century ago when it was discovered that small amounts of the element contributed a natural color and fluorescence to dentures. Restoration of natural appearance is one of the major reasons for using prostheses. Other substances have been found to imitate these characteristics over a broad range of daylight and artificial lighting conditions. The concentrations of uranium required were considered trivial and easily qualified for a licence exempt status when controls were imposed in the 1960's on the use of source material in ceramics. Under regulations of the U.S. Nuclear Regulatory Commission, neither domestic nor imported teeth and powders may contain in excess of 0.05 percent by weight of uranium (CFR, 1986a). Dental products also contain naturally occurring radioactive potassium but there are no controls over the potassium content in these products.

A study by O'Riordan and Hunt (1974) in Great Britain indicated that porcelain teeth containing 0.10 percent uranium could deliver an annual dose equivalent to the oral mucosa of almost 6 Sv (600 rem) by alpha particles and 0.028 Sv (2.8 rem) by beta particles. This estimate is in close agreement with a more recent study by Papastefanou *et al.* (1987) in Greece in which it was reported that uranium concentrations of 500 ppm could yield a surface dose equivalent of about 4 Sv (400 rem) per year. In a study of dental products in the U.S. (Thompson, 1976), the highest concentration observed, 0.044 percent, was calculated to deliver an annual mucosal dose equivalent of 1.3 Sv (130 rem) from alpha emissions. However, the maximum range of alpha particles in tissue is 30 $\mu$m so that most of their energy is expended in the superficial cells overlying the sensitive basal layer. Saliva, dental pellicle, calculus, food, and tobacco residues in the mouth further reduce the intensity of the alpha flux to a level where it does not appear to present a significant hazard.

Beta particles can penetrate in tissue to a depth of 200 $\mu$m. The combined beta emissions of uranium and potassium-40 for the highest concentration sample observed in a study by the Bureau of Radiological Health, were calculated to deliver an annual dose equivalent of 9 mSv (0.9 rem) to the basal layer. The average concentration of uranium in U.S. dental porcelain was estimated to be 0.02 percent. This corresponds to a uranium beta dose equivalent rate of about 5 mSv (0.5 rem) per year. The potassium-40 contribution generally ranged from 1.4 to 1.9 mSv (0.14 to 0.19 rem) per year.

As of 1971, over 19 million persons in the United States were estimated to wear full dentures and 60 million to wear crowns (DHEW, 1962, 1971). Some 90 million persons were missing at least one tooth although it is not known how many wore bridges or partial dentures. More recent published estimates are not available; however, knowledgeable sources in the dental industry indicate that 40 percent of new dental prostheses contain porcelain, and that uranium is no longer used in porcelain by domestic manufacturers (ADA, 1986). The balance of dental products are acrylics and do not contain uranium.

If it is assumed that 45 million people are wearing dental prostheses with an average concentration of 0.02 percent uranium, and that only beta dose need be considered, they will receive a dose equivalent to 7 mSv (0.7 rem) to the basal mucosa. The contribution from this source to the average annual population dose equivalent to the basal mucosa of the mouth would be estimated to be about 1.3 mSv (0.13 rem). On the basis of a weighting factor of 0.01 for the human skin, and assuming that irradiation of the basal mucosa is equivalent to irradiation of 1 percent of the skin, the weighting factor for irradiation of the basal mucosa could be estimated to be 0.01 × 1 percent or $10^{-4}$. The resulting annual collective effective dose equivalent to the U.S. population from this source would be 31.5 person-Sv (3,150 person-rem). This dose is expected to decrease over time as porcelain without uranium displaces the old porcelain containing uranium for use in dental prostheses.

**3.2.7.5** *Uranium and Thorium Impurities in Ophthalmic Glass.* Ophthalmic glass is used to manufacture lenses for eyeglasses and eyepieces. At present, up to 0.05 percent by weight of source material (uranium or thorium or any combination of these materials) may be contained in any chemical mixture, compound, solution, or alloy without NRC regulation or license requirements. There is a further maximum allowable limit of 0.25 percent by weight of source material in rare earth mixtures and products (CFR, 1986c).

Pecora and Munton (1974) have reported that ophthalmic lenses, tinted by adding thorium salts, can be a source of radiation. They tested rose-tinted lenses from several manufacturers and concluded that the dose-equivalent rate to the corneal epithelium from alpha radiation was 0.1 to 0.3 mSv/h (10 to 30 mrem/h). At a depth of 0.2 cm, the beta dose-equivalent rate was calculated to range from 0.7 to 2 μSv/h (0.07 to 0.20 mrem/h) with a gamma dose-equivalent rate to the entire eye of 0.06 to 0.3 μSv/h (0.006 to 0.030 mrem/h). Another study (Yaniv, 1974) reported thorium concentrations of up to 0.14 percent by weight in some samples of ophthalmic glass, with large variations in natural thorium and uranium content for different batches of glass.

Thorium has been shown (McMillan *et al.*, 1975) to exist as an impurity in the rare earth oxides that are used in the manufacture of certain ophthalmic glasses. The thorium content was found to exceed the limit specified in federal regulations (CFR, 1986a) by as much as a factor of ten. These oxides, and their impurities, are generally thought to be the primary source of radioactivity in certain ophthalmic glasses.

Dose calculations by Tobias and Chatterjee (1974) indicate that the annual alpha-particle dose to the critical tissues of the germinal cell layer of the cornea (50 μm), from eyeglasses containing 0.05 percent by weight of $^{232}$Th in equilibrium with its decay products and worn for 16 hours a day, is 2 mGy (0.2 rad) (estimated to be accurate within a factor of two), with an approximately equal absorbed dose from beta particles. Using these data, and applying a quality factor of 20 for alpha radiation, Casarett *et al.* (1974) estimated that the dose-equivalent rate to the germinal cells of the cornea (50 μm depth) would be approximately 40 mSv/y (4 rem/y). The dose-equivalent rate at 60 μm tissue depth was estimated to be 10 mSv/y (1 rem/y). The beta dose-equivalent rate would be a small fraction of this, however, because of the much smaller quality factor of this radiation.

The Yaniv (1974) study concluded that the radiation dose rates from the ophthalmic glass could be reduced significantly with better quality control of the rare earth and zirconium oxides. Another problem revealed by this study was that the observed radiation is not directly related to the source material content of the glass, due to widely varying daughter-parent equilibrium conditions. The radiation emissions are, in fact, mainly due to the short-lived decay products of $^{232}$Th and $^{238}$U, which can be present in glass even after the parent radionuclides are removed. Thus, control of source material content is not sufficient to eliminate radioactive material from glass. Yaniv recommended that new regulations for ophthalmic glass be established on the basis of emission rates rather than on the abundance by percent of weight of the parent nuclide. The Optical Manufacturers Association, with the assistance of the U.S. Nuclear Regulatory Commission and other governmental agencies, has established a voluntary radiological standard for ophthalmic glass (OMA, 1975).

In 1977, about 96,000,000 persons in the U.S. wore eyeglasses (BOC, 1979). Currently, it is estimated that about half of the eyeglasses in use in the U.S. contain plastic lenses which do not contain radioactive material. The same is true for plastic contact lenses (Buckley *et al.*, 1980). As a result, the current estimate of the number of people who are wearing eyeglasses with glass lenses in the U.S. totals about 50,000,000. Assuming an annual dose equivalent of 40 mSv (4 rem) to the cornea at 50 micrometers depth, and assuming a tissue weighting factor of $\leq 10^{-4}$, the annual collective effective dose equivalent to the U.S. population would be about ≤200 person-Sv (≤20,000 person-rem).[5]

### 3.2.8 *Thorium Products*

Thorium is used in optical glass, gas mantles, tungsten welding electrodes, and in various metal alloys. Approximately 250,000 pounds of thorium were used for these purposes within the United States during 1972.

**3.2.8.1** *Thoriated Optical Glass.* Thorium is added to optical instrument glass in concentrations up to 30 percent by weight to provide certain optical properties. Specifically, glasses having an index of refraction greater than 1.65 or with a product of Abbe number and index of refraction greater than 70 are often made with glasses of high thorium content.

The most abundant isotope of natural thorium, $^{232}$Th, is the very longlived parent of the "thorium series." The presence of the decay products in equilibrium with the parent produces alpha-emission rates six times the parent emission rate. Along with the alpha emissions, a very significant beta- and gamma-emission rate also exists.

The use of thorium in optical glass raises few problems unless the glass is used for an eyepiece in an optical instrument. The alpha and beta radiations are easily stopped by almost any lens enclosure. However, the direct exposure of the eye to a lens at a close distance for long periods of time can deliver a significant dose to the outer tissues of the eye. The use of these special optical glasses near the eye is not authorized under the exemptions issued by the U.S. Nuclear Regulatory Commission (CFR, 1986c). However, cases have been reported of eyepieces containing large quantities of thorium (McMillan and Horne, 1973). These thoriated eyepieces were without labels or specifications indicating that thoriated glass was used. The extent to which these lenses are used (deliberately or inadvertently) for eyepieces in optical instruments is not known.

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[5] There are no reported radiation induced cancers of the cornea. Based on this observation, a weighting factor of $\leq 10^{-4}$ has been considered appropriate for estimating the effective dose equivalent due to exposures of this organ.

Casarett *et al.* (1974) have calculated the dose-equivalent rate delivered to the critical tissue (50 to 60 μm depth) of the eye. They assumed that the eyepiece of an instrument that was used for 20 hours per week by a professional user was made from glass with 16 percent $^{232}$Th in equilibrium with its daughters. By also assuming an air gap distance of 0.1 cm between the lens and the outer surface of the lacrimal layer of the eye, they calculated the annual absorbed dose to the critical tissue of the eye at 50 and 60 μm depth to be 0.44 and 0.18 Gy (44 and 18 rad), respectively. With the assumption that the quality factor for alpha particles is 20, the corresponding dose-equivalent rates to the eye are 8.8 and 3.0 Sv/y (880 and 360 rem/y), respectively. Eyepieces made from glass having 0.05 percent thorium may be expected to yield a dose-equivalent rate of approximately 30 mSv/y (3 rem/y) at 50 μm depth.

McMillan and Horne (1973), after having discovered that these lenses were being used as eyepieces, made similar calculations. Their calculated results agree with those of Casarett *et al.* to within 20 to 40 percent. They also confirmed by laboratory measurement the accuracy of their calculated fluence rates at the surface of the glass. One measurement of a lens containing 18 percent thorium by weight yielded a dose rate at the surface of 10 μG/h (1 mrad/h). The number of such lenses in use is unknown although it is probably small. An estimate of the average annual population dose equivalent is not possible.

**3.2.8.2** *Gas Mantles.* The mantles in gas-lanterns and gas yard lights consist almost entirely of the oxides of thorium (95 percent), magnesium, aluminum, cerium, beryllium, and silicon. These mantles are the major incandescent element in such lanterns. During their initial curing, they release about 50 percent of their stable beryllium oxide and many of the decay products of thorium into the atmosphere (Griggs, 1973). Although beryllium probably represents the greater health hazard, because of its chemical toxicity to the lungs, alpha and gamma radiation associated with the thorium oxide can also result in radiation exposure to the user.

Recent reports indicate that about 25 million thorium gas mantles are distributed annually in the U.S. (O'Donnell and Etnier, 1981 and Buckley *et al.*, 1980). Approximately 85 percent are used in portable lanterns (*e.g.*, camping), 8 percent in residential and commercial outdoor lights, 5 percent in residential indoor lights and 2 percent in recreational vehicles. The collective dose rate estimates for transportation, distribution, and use of these devices are about 9 person-Sv/y (900 person-rem/y) (Buckley *et al.*, 1980) and 40 person-Sv/y (4,000 person-rem/y) (O'Donnell and Etnier, 1981). The major differences are due to an estimate by O'Donnell and Etnier of a dose of 10 person-

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