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ESTIMATES OF POTENTIAL RADIATION DOSES FROM WRISTWATCHES CONTAINING TRITIUM GAS

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ABSTRACT

Potential radiation doses were estimated for the United States population from normal distribution, use, repair, and disposal of wristwatches containing up to 200 mCi of tritium (H-3) gas in sealed glass tubes which function as self-luminous light sources. The maximum annual total-body dose was calculated to be 0.3 mrem during watch distribution. Watch wearers were estimated to receive annual total-body doses in the range 0.003 mrem to 0.02 mrem. The total population dose from an annual distribution of one million watches was estimated to be 490 man-rem, with approximately 10 man-rem due to distribution, 225 man-rem due to use, 1 man-rem due to repair, and 250 man-rem due to disposal of these watches. Individual dose ranges were calculated for exposures resulting from accidental tube breakage. Conclusive estimates of such doses, however, could not be made for these situations, due to lack of pertinent data.

SUMMARY

Wristwatches containing as much as 200 mCi of tritium (H-3) gas per watch in sealed glass tubes which function as self-luminous light sources are available to the public. This report presents estimates of potential radiation doses to members of the general public, both individually and collectively, from exposures to such watches.

Dose estimates are based on hypothetical, but believed typical exposures to H-3 potentially released from the watches. Lack of data necessitated the adoption of assumptions about some important exposure mechanisms. These assumptions include: (1) instantaneous association of all H-3 with water vapor (forming HTO) as it leaks from watches; (2) H-3 leakage from watches at a rate of 50 nCi/day; (3) room ventilation rates of one air change/hr; and (4) instantaneous and uniform dispersion of H-3 throughout volumes into which it may be released.

Many of these assumptions are conservative (i.e., tend to overestimate the potential dose) in nature. The assumption that H-3 leaks from watches as HTO could lead to dose estimates that are high by a factor of 1000. (While in the tubes, more than 99% of the H-3 is in elemental or gaseous form.) For accidental tube breakage, conversion of elemental H-3 to HTO was considered to range from zero to 100%, since such H-3 releases would be rapid when compared with normal leakage and H-3 would contact fewer surfaces catalyzing this conversion before escaping from the area. Tritium leak rates generally appear to be lower than the 50 nCi/day assumed, and it is doubtful they would exceed the assumed value by more than a factor of two.[1] Reported leakage measurements are highly variable, and thus, a conservative value for the H-3

leak rate was chosen. Most buildings other than homes will have ventilation rates exceeding the one volume change per hour assumed, which would reduce proportionately the potential doses to exposed occupants of these buildings containing H-3 bearing watches. Although the assumption of a uniform H-3 dispersion within an enclosure, as opposed to a concentration gradient out from the wearer, may underestimate individual doses to those closest to watches, it would tend to overestimate either doses to those in the same room or the number of individuals exposed but not wearing the watches. Thus, population doses would probably not be greatly underestimated by this assumption.

All stages in the life cycle of wristwatches after manufacture were considered. Several groups of people, and models of their involvement, were identified for consideration during distribution, use, repair, and disposal for an assumed distribution of one million watches per year. Some accidental situations were also assessed with respect to potential individual dose ranges.

Table A summarizes potential individual and population doses as calculated under the assumptions used in this report. Except for a very conservative disposal situation, no person is predicted to receive an annual average dose to total body, the critical organ for tritiated water (HTO), in excess of 0.3 mrem from normal activities (the maximum dose to watch wearers being estimated at 0.02 mrem per year). A person who remains for one year at 100 m from a ground level fire in which 8000 watches per year are destroyed could receive 17 mrem from inhalation and absorption through skin. This is clearly a highly improbable exposure situation. Under certain accident conditions, individual doses between 0.5 mrem and one rem may be calculated for breakage of a gas tube, depending on the extent of conversion of H-3 gas to HTO, which would probably be low under assumed conditions.

The total population dose could be about 490 man-rem per year under the assumed conditions. About 200 man-rem could be due to burning of discarded watches. About 225 man-rem could be received by wearers and persons who occupy the same rooms as wearers.

Better data on isotopic exchange and oxidation of H-3 gas to form HTO would be useful. Available data indicate that HTO forms slowly, except in situations where the watches are burned. Therefore, doses given in this report may be overestimated since total conversion to HTO is assumed. The upper dose limits from breakage of tubes may be high by a factor of 100; those from normal leakage, by perhaps a factor of 1000. Rapid oxidation is likely, however, in a fire situation. Thus, the population dose due to disposal by burning may not greatly overestimate potential doses.

Table A. Summary of potential radiation dose estimates for LCD wristwatches containing gaseous tritium

Stage and groups of exposed persons	Section reference	Individual doses, mrem/year (range)	Population doses,[a] man-rem/year
Distribution	4.1		
Parcel delivery workers		3×10^{-5} to 3×10^{-1}	<<1
Marketers		4×10^{-4} to 1×10^{-1}	6
General public		8×10^{-7} to 1×10^{-5}	3
Use	4.2		
Wearers		3×10^{-3} to 2×10^{-2}	65
Bystanders		3×10^{-3} to 2×10^{-2}	160
General public		0 to 3×10^{-6}	1
Repair	4.3		
Repairmen		3×10^{-2} to 6×10^{-2}	~1
Disposal	4.4		
Storers		2×10^{-3} to 3×10^{-3}	50
General public		0 to 17	200
Accidents	4.5		
Owner (at home)		~0.5 to 50	na[b]
Repairman		~10 to 10^3	na
Warehouseman		~ 1 to 10^2	na
Total			486

[a]Based on an annual distribution and disposal of 1×10^6 watches, each with a 10 year lifetime.

[b]Population dose not estimated because accident probabilities are unknown. They are believed to be very low.

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1. INTRODUCTION

Wristwatches with digital time displays are becoming increasingly popular. This popularity has prompted development of improved digital time display systems. One such system incorporates a liquid crystal display (LCD) which is illuminated continuously by a self-luminous, background light source, thus, eliminating the need for a manually-operated, battery-powered, auxilliary lighting system. This light source contains tritium (H-3) gas.

Members of the general public may be exposed to H-3 during the entire life cycles of these wristwatches, including the time during which they are in a disposal facility. This report presents estimates of potential radiation doses to selected individuals and to the population of the United States from distribution, use, repair, and disposal of the watches and from accidents involving them.

A brief description of, and pertinent information concerning, the wristwatches are given first. This is followed by a brief description of the assessment methodology and strategy. Finally, each stage in the life span of a timepiece is discussed in terms of possible exposure scenarios and resultant radiation doses to individuals and population groups. Details of assumptions concerning the exposure scenarios are presented in order to qualify the resultant dose estimates.

2. PRODUCT DESCRIPTION AND INFORMATION

Each LCD wristwatch assessed contains initially between 160 and 200 mCi of H-3 gas (nominal composition according to watch manufacturers: elemental > 99%, oxide < 1%) in two sealed borosilicate glass tubes. A typical tube is approximately 2.0-cm long with a 0.3-cm x 0.08-cm elliptical cross-section and a 0.02-cm thick wall. An inorganic phosphor coats the inside surface of the tube. Light is produced when the phosphor is activated by beta particles emitted during radioactive decay of the contained H-3.

The tubes are well protected in a completed watch and are not easily accessible. Both tubes are bonded to a metal tray with a shock-absorbent silicone adhesive. The tray is sealed to a transflector-display panel and the entire assembly is encapsulated in a plastic collar. A printed circuit board is affixed to the plastic collar, covering the bottom of the tray. This module is inserted into a watch case as an integral unit.

Repair and servicing of the wristwatches will likely be restricted to battery replacements and minor electronic circuit adjustments. Disassembly of the time display module is not anticipated (as a normal occurrence) because of economic and technical limitations. Defective modules will likely be replaced by the manufacturer.

The anticipated useful life of a backlit LCD wristwatch is about ten years. Confirmation of this lifetime will require additional use experience, because these watches have been distributed only during the last few years.

Forecasts of the potential market for LCD wristwatches are not well developed at this time (August 1977). Based on manufacturers' estimates, several million watches may be distributed over the next few years.

Annual production could range between one and five million units after a few introductory years. However, as in all highly competitive industries, changes in consumers' preferences or introduction of different product designs could alter significantly forecasted market demands.

3. ASSESSMENT STRATEGY

Potential radiation doses from H-3 in backlit LCD wristwatches were estimated utilizing the CONDOS methodology[2] and the AIRDOS-II computer code.[3] The life spans of wristwatches were divided into five stages: distribution, use, repair, disposal, and accidents. Potentially exposed groups of persons were identified in each stage, and conditions were postulated under which typical group members (individuals) could be exposed to the H-3 contained in or released from the watches. Using these exposure conditions, individual doses were calculated. Population doses, except those from disposal, were estimated by assuming that all group members receive similar doses to that received by the individual selected as typical of the group.

In general, potentially exposed persons were identified and their conditions of exposure were constructed from information contained in the NRC licensing files and derived from interviews with distributors and users of wristwatches. It is felt that the exposure scenarios used in this assessment are reasonable, sometimes conservative, representations of typical, real-life conditions. However, because other exposure conditions are possible and because of the direct dependence of the dose estimates on them, all assumed exposure conditions are described to make clear the bases on which the dose estimates were made.

A basic assumption is that H-3 must escape from the watches in order to become a potential source of exposure. This assumption is valid because the 0.0186-MeV beta particles emitted during radioactive decay of H-3 are not sufficiently energetic to penetrate the glass tubes, and because any low-energy bremsstrahlung produced during stopping of the beta particles in the tubes would be absorbed by the watch cases.

Tritium may escape from the watches via leakage through (diffusion or permeation), or breakage of, the glass tubes. Breakage would likely occur only during severe accidents or during disposal of watches, and would likely result in complete release of any contained H-3. Leakage is a normal, apparently slow, process. Based on data supplied by watch and tube manufacturers, the H-3 leak rate will not exceed 100 nCi/day per watch; will normally be less than 50 nCi/day per watch; and could be much lower.[1] In this report, all doses were estimated using a leak rate of 50 nCi/day per watch, except where indicated.

The chemical form of airborne H-3 at the time of exposure is very important with respect to calculated doses. Doses from exposure to a concentration in air of elemental H-3 would be lower by at least a factor of 10^3 than those from exposure to the same concentration of HTO in air.[4,5] This is due to the low retention of H-3 gas in the body subsequent to inhalation and to relatively insignificant percutaneous absorption of the gas. Tritium which leaks from the tubes will likely be in elemental form. In time, elemental H-3 will be incorporated into water vapor either by isotopic exchange or by direct combination with oxygen.[6,7]

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Before leaking from a watch, this H-3 will probably contact many surfaces which catalyze oxidation. Unfortunately, the reaction rates of these processes are largely unknown. Factors which may affect the rates include the concentration of H-3 in air and the availability of catalysts (e.g., metal surfaces).[7] At high H-3 concentrations (>1 mCi/cc) the reaction rates, although favored, are apparently slow (half-time > 96 hr).[7,8] At lower concentrations (between 10^{-4} mCi/cc and 1 mCi/cc), the reaction rates have been found to decrease further.[7,8] However, fluctuations in available data at these lower concentrations[8] prohibit extrapolation of a conversion rate to be used in this study, where H-3 concentrations are less than 10^{-10}mCi/cc under normal use situations. For this reason, a conservative approach has been taken, and it has been assumed that H-3 leaks from watches as HTO under normal circumstances. This assumption would likely overestimate (by up to a factor of about 1000) doses to persons in confined spaces (rooms) but should have less of an affect on estimates from releases to the outdoors (i.e., from disposal). In the case of accidents, no assumptions about conversion rates were made since catalysis by metal would be less likely and room ventilation would vent released H-3 rapidly. Ranges of doses are given for zero to 100% conversion of elemental H-3 to HTO.

For lack of a firm estimate of LCD watch distribution, this assessment assumes distribution of one million watches per year; ten million watches in use during the year (derived from an assumed 10-year lifetime); and an annual disposal of one million watches. Radioactive decay of H-3 is neglected except for disposal, when it is assumed that the watches have been used for ten years and the H-3 content is reduced. These numbers were chosen as convenient references from which to scale the dose estimates upon quantification of the distribution of backlit LCD wristwatches.

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4. EXPOSURE CONDITIONS AND DOSE ESTIMATES

4.1 Due to Distribution

Interviews with several retailers, a wholesaler, and an importer of timepieces indicated that parcel delivery is the major, if not the sole, method used to deliver timepieces from manufacturers or assemblers to wholesalers or retailers. Persons employed in parcel delivery (truck drivers and terminal workers) may be exposed to air concentrations of H-3 which has leaked from watches being distributed. Exposures may also occur at the wholesale and retail levels for warehouse or stockroom clerks, salespersons, and customers.

Table 1 summarizes exposure conditions used in estimating potential radiation doses to the exposed population groups. Information used in postulating the exposure conditions was obtained from personal communications with parcel delivery system employees, local merchants, and a wholesaler.

General assumptions used in construction of exposure scenarios for parcel delivery system employees include:

1. A local truck driver picks up a shipment of 800 watches from the same manufacturer or assembler each day (250 days/year). The driver spends 0.5 hr/day in the cargo compartment while an equilibrium air concentration of H-3 is present. Each of five drivers were assumed to pick up 200 thousand wristwatches per year.
2. A shipment of watches travels an average distance of 1200 km (750 miles) from the point of pick up to the wholesaler or retailer. Shipments of this length involve both regional (between parcel delivery terminals) and local deliveries.

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3. Terminals are located 400 km (250 miles) apart. Thus, a shipment of watches passes through four terminals. A regional driver transports watches between terminals but does not enter the cargo compartment (trailer) of the truck. Three drivers are required per shipment.
4. Half of the shipments are kept overnight (8 hr) in a terminal; the other half remain in trailers. Two shift supervisors are in the terminal for the entire eight hours, and 70 part-time shift workers are present for three hours each.
5. Local truck drivers deliver shipments to wholesalers or retailers. Each of 625 drivers delivers two shipments per year.
6. The numbers of exposed persons and watches in a location, as well as durations of exposure are based on the following scheme: (i) five local terminals each process one shipment of 800 watches per day (250 shipments per year) and forward them equally to five regional terminals; (ii) each of the 25 regional terminals processes 50 shipments per year and forwards them equally to five other terminals; (iii) these terminals, 125 of them, each process ten shipments annually and forward them equally to five final terminals; (iv) the 625 final terminals process two shipments per year and deliver them to wholesalers or retailers.

Exposure scenarios for marketing include typical building dimensions, occupancy factors, and average numbers of watches likely to be present in the various locations. These scenarios are based on personal observations and the sources cited above. It was assumed that one-half of the watches went through the wholesale market, and, thus, additional truck drivers were involved for transporting watches to retailers.

Table 2 summarizes potential doses to various groups of persons under the postulated delivery and marketing schemes. To obtain the doses, each watch was assumed to leak H-3 as HTO at a rate of 50 nCi/day and the vapor was assumed to disperse uniformly and very rapidly throughout the specified volume (Table I). Air change rates were taken to be one volume per hour for buildings and two volumes per hour for trucks.

Local truck drivers who pick up shipments could receive an average annual total-body dose of 0.3 mrem. All other parcel system workers will likely receive less than 0.01 mrem/year. As a group, parcel delivery workers could receive about 0.01 man-rem/year.

Some marketing employees could receive as much as 0.13 mrem/year, but most workers would likely receive less than 0.005 mrem/year. Annual doses to individual customers would likely be very low. The population dose associated with marketing could be 9 man-rem/year.

The magnitude of the population dose from marketing is attributable largely to the number of potentially exposed persons, particularly clerks and customers in department stores. Eight million department store clerks were considered, and every person in the United States (210 million) was assumed to spend 1 hr/week in a department store.

As noted in Sect. 3, if the maximum anticipated leak rate were assumed, the doses given in Table 2 could be doubled. However, the assumption that all H-3 leaks from watches forms HTO immediately could cause the given doses to be too high by as much as a factor of about 1000.

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4.2 Due to Use

Backlit LCD wristwatches will likely be used as are any other watches and will be distributed according to population densities. For purposes of assessment, the population of the United States was divided into three categories: (1) wristwatch wearers, (2) bystanders, and (3) distant persons.

Several types of wearers may exist. The ten million wearers of LCD wristwatches are assumed to be of three types: (1) 1.2 million persons who work in office-type situations for eight hours per work day and are at home 16 hours per day, (2) 3.8 million persons who work outdoors or in well ventilated areas and are at home 16 hours per day, and (3) 5.0 million persons who spend 24 hours per day in a home-like environment. The number of persons of each type were arbitrarily chosen by assuming half the wearers work away from home. The number of office-type workers was calculated from data compiled by the Bureau of the Census.[9] These data indicate that about 12% of the population works eight hours per day in an office-like environment.

Bystanders are persons who work near, live with, or associate with wearers of the watches. Three such persons are assumed to be in the vicinity of each wearer. Distant persons are those sufficiently distant from wearers' immediate environs that any H-3 released from watches has been diluted with ambient air before exposure occurs.

Table 3 summarizes exposure conditions assumed for each type of person. (The three common assumptions are not stated explicitly, viz., H-3 leaks from each watch at a rate of 50 nCi/day, all leaked H-3 is in the form of water vapor, and the H-3 disperses rapidly and uniformly throughout the volume.) Exposure locations room volumes, exposure durations, and equilibrium air concentrations of H-3 are given. One watch was assumed in each location and room ventilation rates were taken to be one air change per hour--as recommended for typical residential units.[10]

Distant persons were treated differently. The AIRDOS-II computer code[3] and meteorological and population data developed for the LMFBR assessment[11] were used to calculate individual and population doses. In this calculation, H-3 leakage was considered to be a ground level release of H-3 which dispersed into the atmosphere and was inhaled by persons within a 80.5-km (50 mile) radius of the release point. The conditions listed in Table 3 pertain to a very large city containing 4% of the U.S. population, such as New York,[9] in which 400,000 watches (4% of ten million) were assumed used by 8.4 million persons (4% of the U.S. population). These watches released about 7.3 Ci of H-3 per year at the center of the population zone. A population dose was calculated for this situation and was extrapolated linearly to obtain a total population dose.

Table 4 summarizes potential individual and population doses from use of LCD wristwatches that contain 200 mCi of H-3 gas. Doses to individuals were calculated to be less than 0.03 mrem/year. The annual population dose from use of ten million wristwatches could be approximately 226 man-rem. Almost three-quarters of this dose could be to bystanders, persons who do not wear watches but associate closely with wearers.

As noted in Sect 3 and 4.1, assumptions regarding the rate of H-3 leakage from watches and chemical form of the released H-3 could significantly affect the dose estimates.

4.3 Due to Repair

Watch repairmen may adjust or replace batteries in the watches. Neither of these operations require handling or removal of the time display module which contains the H-3 tubes. Other repair operations are not likely because of economic factors.

Because of limited access to the H-3 tubes and the secure construction of the module, it is unlikely that H-3 will be released catastrophically from watches during repair, normal leakage will continue, of course. The unlikely breakage of tubes in a shop is considered in Sect. 4.5.

Based on personal communications with several watch repairmen, the following exposure scenarios are used to estimate radiation doses to repairmen. Two sizes of repair shops are considered.

Five thousand (one-third of approximately 15,000 watch repairmen in the United States[12]) were assumed to work in large repair shops. The remaining 10,000 work in small shops.

A large shop was assumed to occupy a volume of 3.4×10^{7} cc and to contain approximately 200 watches of all types. About four, or 2%, of these could be LCD watches. (About 50 million watch movements are sold per year in the United States[13] and one million LCD watches comprise about 2% of the total.) Under the usual assumptions, this could lead to an equilibrium concentration of 2.5×10^{-10} μCi of H-3/cc of air. A repairman working in such a shop for 2500 hr/year (10 hr/work day) could receive an average annual total body dose of 0.06 mrem. Five thousand repairmen could receive a collective dose of about 0.3 man-rem.

A small shop was assumed to occupy 1.8×10^7 cc and to contain an average of 50 watches, or one LCD watch. The resultant air concentration could be about 1.2×10^{-10} μCi/cc. If a repairman works in such an environment for 2500 hr/year, he could receive, with the usual ca tions regarding leak rate and H-3 behavior, about 0.03 mrem/year average to total body. Ten thousand repairmen could, therefore, receive an annual population dose of 0.3 man-rem.

4.4 Due to Disposal

A ter ten years of use, LCD wristwatches were assumed to cease functioning. At this time, radioactive decay would have reduced the H-3 content of each watch from 200 to 120 mCi. Therefore, about 120,000 Ci of H-3 will be disposed of at this time.

Ordinarily, obsolete timepieces will either be stored indefinitely by the owner or be discarded as municipal solid waste. If discarded, about 50% could be burned[14] and 50% buried in a landfill. If burned or incinerated, discarded watches will release their entire H-3 inventory immediately. If stored or buried, watches will continue to release H-3 by leakage, but at a reduced rate (viz., 30 nCi/day). Storage and burial are considered equivalent in terms of a general population dose.

In this instance, it was assumed that 50% of the obsolete watches are stored for an average time of 5 years, and 50% are discarded. Therefore, 500 thousand watches are put in storage annually. Thus, 15 years after initial distribution of these watches, 2.5 million may be in storage, 500 thousand may be burned, and 500 thousand may be buried each year, assuming that 500 thousand are discarded annually subsequent to a 5-year storage.

Exposures to watches stored in a home would be similar to those from use of watches. Tritium would continue to leak from the watches (30 nCi/day). Persons in homes could be exposed to air concentrations of 3.7×10^{-12} μCi of H-3/cc for between 5840 and 8760 hr/year (Sect. 4.2). Tritium could also escape into the atmosphere and expose the general population.

Using procedures similar to those of Sect. 4.2, each of 2.5 million former wearers and 7.5 million bystanders (family members) could receive about 0.002 mrem/year from being in a home for 5840 hr/year. Another ten million persons could each receive 0.003 mrem/year from being in a home for 8760 hr/year. Distant persons could receive as much as 1.6×10^{-6} mrem/year. The population dose could be about 50 man-rem/year from storage of 2.5 million obsolete wristwatches.

Burial of 500 thousand wristwatches/year was assessed by considering burial of 4% of the watches (20,000) in a landfill at the center of 8.4 million persons. After 10 years of use of this landfill, up to 200,000 watches could be buried. If no H-3 gas-containing tubes break, approximately 2 Ci of H-3 could escape from a ground level source to the atmosphere during the year. The maximally exposed individual, who is assumed to be 100 m from the release point all year could receive an average dose of about 0.1 mrem/year to total body. The population dose to 8.4 million persons could be about 0.06 man-rem/year. Considering all buried timepieces (5 million), the population dose could be about 1.2 man-rem/year.

Of the 500,000 watches/year assumed to burned, 100,000 are assumed incinerated and 400,000 burned at ground level sites. These assumptions could result in release of 1.2×10^4 Ci/year of H-3 from incinerator stacks and 4.8×10^4 Ci/year of H-3 from ground level sources. Using these assumptions, the AIRDOS-II computer code[3] with LMFBR exposure conditions,[11] and the large city assumptions, ground level burning could result in a potential dose of 17 mrem/year to the previously defined, hypothetical, maximally exposed individual. The resultant population dose could be approximately 170 man-rem. Incineration of watches would not produce individual doses higher than those given for ground level burning. The population dose from incineration of 100,000 watches could be 25 man-rem.

To summarize, the following potential doses could be realized from disposal. Under most adverse conceivable conditions, an individual could receive as much as 17 mrem/year. Most individual doses would be much lower. The total population dose could be approximately 250 man-rem/year. Most of this dose is due to H-3 released to the atmosphere by burning and subsequently inhaled, absorbed, and ingested by man. It should be noted that oxidation of H-3 gas to water vapor would be rapid in the presence of fire.

4.5 Due to Accidents

Accidents in which the glass tubes containing H-3 could be broken and the H-3 released to the environment, although unlikely, are of 307 100 concern in the assessment of LCD wristwatches. Three accidents were postulated and corresponding exposure scenarios were constructed. Probabilities of occurrence were not estimated but are believed to be very low.

Since the accident situations considered involve an instantaneous release of previously contained H-3 into the respective environment, complete conversion of elemental H-3 to HTO was not assumed. From available literature, it is doubtful this conversion would be complete for the time frames dealt with in the following scenarios (see Sect. 3). Thus, dose ranges were calculated for individuals potentially exposed to accidently released H-3. Lower values represent exposures to H-3 of which 99% is in elemental form, and 1%, in oxide form (i.e., no conversion takes place), and upper values represent exposures to H-3 of which 100% is in the oxide form (HTO). Actual doses would be somewhere between these two values, depending on the conversion rate in question. Available data indicate that the doses would likely be near the lower values.

If a wristwatch were crushed in a home (volume = 3.4×10^8 cc) and all 200 mCi of H-3 were released, then, under the usual assumptions, the average concentration of H-3 in the home during the subsequent 24 hr could be about 2.5×10^{-5} μCi/cc. A person in the home for the 24 hr could receive a dose in the range of 0.5 to 50 mrem.

The average concentration ($\overline{C}$) of H-3 in a ventilated room with no additional input of H-3 is given by:

$$\overline{C} = (It)^{-1}C_o(1-e^{-It}),$$

since

$$C = C_o(e^{-It}).^9$$

I is the air exchange rate (volume changes/hr), t is the time (hr) period of interest, and C_o is the concentration (μCi/cc) of H-3 at t = 0. In this assessment, I is taken to be 1.0 change/hr.

Breakage of two tubes (200 mCi of H-3) in a small repair shop (volume = 1.8×10^7 cc) with an air exchange rate of one volume/hr could result in an average air concentration of 1.1×10^{-3} μCi of H-3/cc over a ten-hour period. The dose to a repairman in the shop for ten hours could range from 10 mrem to one rem, again depending on the amount of H-3 gas converted to HTO.

Finally, a fire in a catalog distribution warehouse (volume = 2.3×10^9 cc) containing 60 LCD wristwatches was considered. If all the watches were destroyed, 12 Ci of H-3 gas would be released. If there was no air exchange for 0.25 hr and equilibrium conditions prevailed, the concentration of H-3 in the warehouse would be 5.2×10^{-3} μCi/cc. A person in the warehouse for 0.25 hr could receive an average dose to total body of between 1.2 and 120 mrem.

In all of the above scenarios, we have assumed immediate equilibrium concentrations of H-3, and room ventilation rates of one air change per hour (except in the last example). These assumptions tend to maximize the dose estimates. Less conservative assumptions could reduce the calculated dose ranges significantly.

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Table 1. Typical exposure conditions during distribution of wristwatches

Exposed group	Exposure activity	Exposure location	Volume of location, cc	Number of wristwatches at location	Concentration of H-3 in air, μCi/cc	Duration of exposure, hr/year
<u>Parcel delivery system</u>						
Local truck drivers	Load/unload	Rear of truck	2.9×10^{7}	800	2.9×10^{-8}	1 to 125
Terminal supervisors	Working	Terminal	1.7×10^{10}	800	9.8×10^{-11}	8 to 1000
Terminal workers	Working	Terminal	1.7×10^{10}	800	9.8×10^{-11}	3 to 375
	Load/unload	Rear of truck	2.9×10^{7}	800	2.9×10^{-8}	0.25 to 31
<u>Marketing system</u>						
Catalog sales						
Warehouse workers	Stocking	Warehouse	2.3×10^{9}	20	1.8×10^{-11}	2000
Store workers	Stocking	Stockroom	3.4×10^{8}	2	1.2×10^{-11}	500
Large jewelers						
Stock clerks	Stocking	Stockroom	1.4×10^{8}	10	1.5×10^{-10}	250
Salespersons	Selling	Store	2.3×10^{9}	10	9.1×10^{-12}	2000
Customers	Shopping	Store	2.3×10^{9}	10	9.1×10^{-12}	1
Small jewelers						
Clerks	Working	Store	1.4×10^{8}	5	7.4×10^{-11}	2000
Customers	Shopping	Store	1.4×10^{8}	5	7.4×10^{-11}	1
Department stores						
Clerks	Working	Store	3.4×10^{9}	5	3.1×10^{-12}	2000
Customers	Shopping	Store	3.4×10^{9}	5	3.1×10^{-12}	52
Wholesalers						
Stock clerks	Stocking	Stockroom	2.3×10^{9}	10	9.1×10^{-12}	500
Salespersons	Selling	Showroom	1.4×10^{8}	10	1.5×10^{-10}	2000
Truck drivers	Load/unload	Rear of truck	2.9×10^{7}	10	3.6×10^{-10}	50

Table 2. Potential doses during distribution of wristwatches

Exposed group	Number of exposed persons	Dose to individual, mrem/year	Population dose, man-rem/year
Parcel delivery system			
Local truck drivers	6.3×10^2	2.6×10^{-3} to 3.2×10^{-1}	3.2×10^{-3}
Terminal supervisors	1.6×10^3	7.0×10^{-5} to 8.8×10^{-3}	3.5×10^{-4}
Terminal workers	5.5×10^4	2.6×10^{-5} to 8.1×10^{-2}	6.2×10^{-3}
Subtotal			9.8×10^{-3}
Marketing system			
Catalog sales			
Warehouse workers	8.0×10^4	3.3×10^{-3}	2.6×10^{-1}
Store workers	3.2×10^5	5.5×10^{-4}	1.8×10^{-1}
Large jewelers			
Stock clerks	4.0×10^4	3.3×10^{-3}	1.3×10^{-1}
Salespersons	4.0×10^4	1.6×10^{-3}	6.5×10^{-2}
Customers	5.3×10^7	8.1×10^{-7}	4.3×10^{-2}
Small jewelers			
Clerks	2.0×10^4	1.3×10^{-2}	2.7×10^{-1}
Customers	5.3×10^7	6.7×10^{-6}	3.5×10^{-1}
Department stores			
Clerks	8.0×10^6	5.5×10^{-4}	4.4
Customers	2.1×10^8	1.4×10^{-5}	3.0
Wholesalers			
Stock clerks	1.0×10^4	4.1×10^{-4}	4.1×10^{-3}
Salespersons	1.0×10^4	2.7×10^{-2}	2.7×10^{-1}
Truck drivers	1.0×10^3	1.3×10^{-1}	1.3×10^{-1}
Subtotal			9.0
Total			9.0

Table 3. Typical exposure conditions during use of wristwatches

Exposed group	Exposure activity	Exposure location	Volume of location, cc	Concentration of H-3 in air, μCi/cc	Duration of exposure, hr/year
Wearers(1)	Working	Office	1.8×10^{7}	1.2×10^{-10}	2000
	At home	Home	3.4×10^{8}	6.1×10^{-12}	5840
Wearers(2)	Working	Outdoors	Infinite	0	2000
	At home	Home	3.4×10^{8}	6.1×10^{-12}	5840
Wearers(3)	At home	Home	3.4×10^{8}	6.1×10^{-12}	8760
Bystanders(1)	Working	Office	1.8×10^{7}	1.2×10^{-10}	2000
Bystanders(2)	At home	Home	3.4×10^{8}	6.1×10^{-12}	5840
Distant persons	Living	Many	Infinite	0 to 9.7×10^{-12}	8760

Table 4. Potential doses during use of wristwatches

Exposed group	Number of exposed persons	Dose to individual, mrem/year	Population dose, man-rem/year
Wearers(1)	1.2×10^6	2.4×10^{-2}	29
Wearers(2)	3.8×10^6	3.2×10^{-3}	12
Wearers(3)	5.0×10^6	4.8×10^{-3}	24
Subtotal			65
Bystanders(1)	3.6×10^6	2.1×10^{-2}	75
Bystanders(2)	2.6×10^7	3.2×10^{-3}	84
Distant persons	1.7×10^8	0 to 2.6×10^{-6}	1
Subtotal			160
Total			225

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HEALTH AND SAFETY RESEARCH DIVISION

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