Supplement to Radium Timepiece Dose Modeling:

Radium Gauge Dose Modeling

SECOND DRAFT REPORT
March 2008

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Prepared for the
U.S. Nuclear Regulatory Commission

ORISE
Oak Ridge Institute for Science and Education

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Introduction

The Energy Policy Act of 2005 amended section 11e.(2) of the Atomic Energy Act of 1954 to define certain accelerator-produced radioactive material and discrete sources of radium-226 (Ra-226) as byproduct material, thus placing them under NRC regulatory authority. Historically, each State had independent jurisdiction over Ra-226 and some States developed regulations for controlling this material. The model State standards provide an exemption for previously acquired timepieces with no more than 1 microcurie (µCi) of Ra-226. The Energy Policy Act of 2005 mandated that the NRC use model State standards, to the extent practicable, in developing its regulations for the expanded definition of byproduct material.

The report entitled *Radium Timepiece Dose Modeling, Revision 1* (ORISE 2007) evaluated potential doses to collectors, users and repairers of timepieces (watches and clocks) that contained Ra-226 in radioluminescent paint. The report adapted the methodologies in NUREG-1717, *Systematic Radiological Assessment of Exemptions for Source and Byproduct Materials* (NRC 2001), to estimate potential doses under a variety of exposure scenarios. Dose calculations included consideration of multiple exposure pathways, including external radiation exposure, inhalation and ingestion of the radium paint, and inhalation of the radon produced by the decay of the radium. This supplement to the timepiece report expands the dose evaluation to consider potential doses to users and possessors of radioluminescent gauges, such as vehicle and aircraft gauges, that contain Ra-226 in the luminescent paint.

Due to the physical similarities between timepieces and gauges, the results from the timepiece dose modeling report can generally be extrapolated to predict doses from radioluminescent gauges under many of the same exposure scenarios. This supplement presents dose estimates for possessors and users of luminescent gauges based on extrapolation of the applicable scenarios from the timepiece report, as well as one new exposure scenario, which is introduced to consider dose to a member of the public from actively using luminescent gauges in a commercial vehicle or aircraft.

History of Ra-226 radioluminescent gauges

Beginning in the early 1900s, radioluminescent paint gained widespread use as a way to make various consumer products glow in the dark. The most common items to use radioluminescent paint were timepieces (watches and clocks), vehicle gauges and aircraft gauges. The paint is created by adding together a radioactive substance, in this case Ra-226 as sulfate, and a luminescent powder. The radiation from the radium interacts with the luminescent powder, and creates a steady glow without the need for electricity.

At the time, little was known about the potential hazards of radioactive material. As more was learned about radioactivity and its potential hazards, the use of radium in paint was gradually phased out. Beginning in the 1950s and 1960s, Ra-226 was replaced with other less hazardous radionuclides such as tritium and promethium-147.

Most luminescent gauges are military in origin, although some were produced directly for civilian use. However, many of the military gauges have since come into public possession through such mechanisms as government surplus supplies auctions, military surplus stores, and souvenir collection stores. Current uses by the public include collection and, much more rarely, active use by installing the gauges in vehicles and aircraft.

Applicability of the timepiece dose modeling results to luminescent gauges

Structurally, dial gauges are very similar to timepieces. Both are normally constructed with a metal casing and clear glass or plastic cover, and enclose one or more movable needles or hands used to indicate a value. Both are usually sealed to varying degrees, with gauges often being hermetically sealed. The radioluminescent paint is typically applied to one or more needles and tick marks inside. Gauges typically have more radioactivity than timepieces due to the larger size of the needle and instrument face.

Due to the similar construction and physical properties, the same calculational methods and parameters used to estimate doses from radium timepieces can be used to estimate doses from radium gauges. In fact, when the exposure scenario is the same, such as for collection or repair of the items, the results for the timepieces can be directly scaled up based on the higher radioactivity levels in the gauges.

Evaluation of gauge radioactivity levels

Due to the limited regulation of radium during the gauge production era (circa 1940s to 1950s) and the significant time that has passed since then, there is limited quantitative data on the radioactivity content of gauges. Many, if not most, of the gauges were produced for military use. Consequently, the military inventory of Ra-226 items is the single largest and most reliable source of data for this assessment. In support of this report, the military provided a listing of over 2000 Ra-226 containing items in its inventory[1]. The listing includes item descriptions along with an estimated Ra-226 activity content. The activity content estimate is based on a combination of gamma spectrometry results, item labels, and historical knowledge[2].

The inventory information provided by the military included many items containing Ra-226, including gauges and other devices designed for use in vehicles and aircraft. The inventory includes non-gauge items such as ammeters, voltmeters, compasses, and various indicators on equipment. However, many of these non-gauge items have similar construction and properties to the gauges of interest in this supplement, and were included for the purpose of estimating radium content in gauges. In general, the criteria for including an item from the military dataset in the activity analysis was that the item contains Ra-226 luminous paint for an indication or readout. Non-readout items such as toggle switches, circuit breakers and control knobs were not included in the activity evaluation.

The vast majority of items in the inventory contained one microcurie or less of Ra-226. There are far fewer devices in the one to 15 microcurie range, and several outliers at much higher activities. The validity of the data for the very high activity devices is uncertain, as it is extremely unlikely that devices would contain Ra-226 activity in these high amounts

[1] Personal communication between P. Frame (ORISE) and Lt. Col. Scott Nichelson (USAF), November 30, 2007.
[2] Personal communication between M. Buchholz (ORISE) and B. Silber (US Army), November 15, 2007.

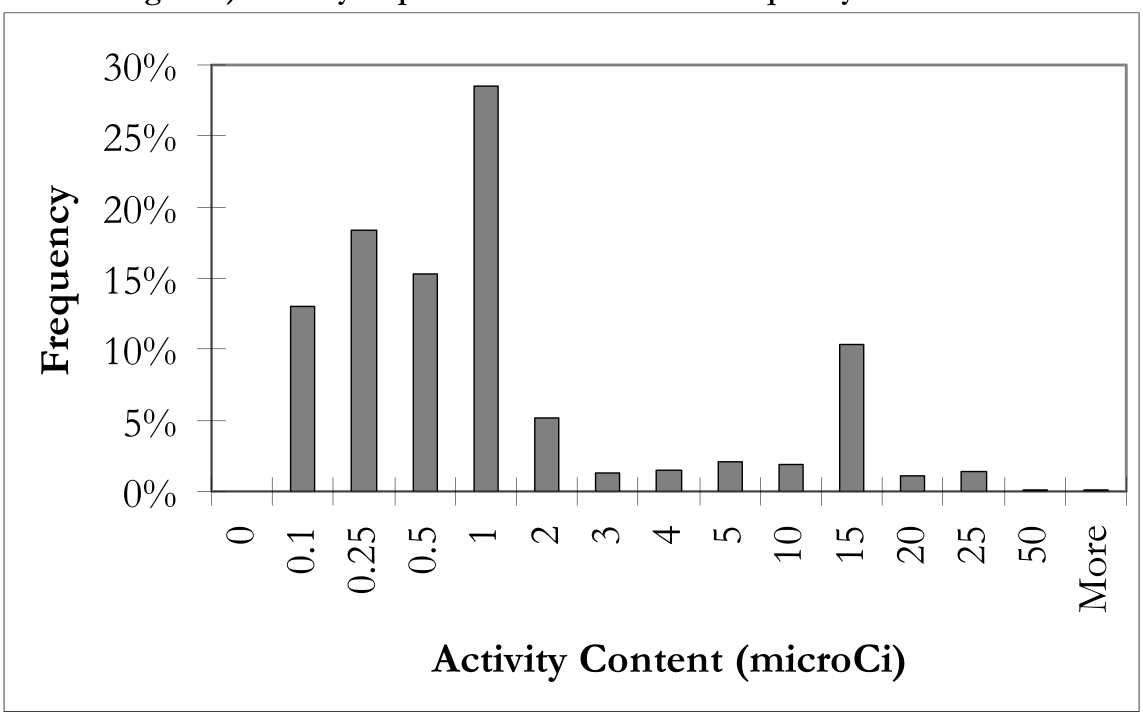
strictly for use in luminescent paint. The mean activity of the devices in the inventory is 3.95 microcuries, but this is heavily influenced by the high-activity outliers. The median activity, which is much more representative of the typical device, is 0.56 microcuries.

Based on the information provided, the activity content of gauge or indicator-like devices containing Ra-226 in the military inventory is summarized as follows:

Table 1) Military Reported Radium Device Activity Summary (Gauges and Other Devices Combined)

	Activity (µCi)
Mean	3.95
Median	0.56
Min	0.0001
Max	1000
Std. Dev.	33.11
75th Percentile	1
90th Percentile	15
95th Percentile	15

Figure 1) Military Reported Radium Device Frequency Distribution



As this data shows, the Ra-226 activity in the military inventory varies widely. However, the dose modeling results in this report are normalized to a one microcurie gauge activity, except where otherwise noted. This allows the results to be scaled to consider the dose from gauges of any activity content. One microcurie also corresponds to the value for exemption from licensing requirements in the NRC rulemaking "Requirements for the Expanded Definition of Byproduct Material".

Scenarios for luminescent gauges

The timepiece report presented nine exposure scenarios by which an individual may reasonably be expected to be exposed to radiation from radium timepieces. However, not all of those scenarios are applicable to luminescent gauges. For example, a gauge will not be worn on the wrist such as a wristwatch, or on the body such as a pocket watch, nor will it likely sit long-term in a family living area. The scenarios from the timepiece report that are applicable to gauges include general collection and storage of gauges, repair activities, and accident-type events such as a fire and subsequent cleanup.

In addition to the scenarios above, an additional exposure scenario is necessary for radioluminescent gauges to consider the dose to a member of the public from actively using one or more gauges in a commercial vehicle or aircraft. While newly manufactured luminescent gauges no longer use Ra-226, there are numerous old Ra-226 gauges that have been refurbished and are used in commercial and private vehicles and aircraft. Of the commercial and private uses, the commercial use is more limiting from a radiological dose perspective due to the longer exposure times of a commercial driver or pilot. Instrument panels could have varying numbers of Ra-226 gauges or other indicators of varying activity content. The results of this scenario are therefore normalized per total microcurie of Ra-226 content in the vehicle or aircraft instrument panel. The calculated dose can then be scaled to predict the resultant dose from any combination of gauge number and activity content. However, it is likely that any one instrument panel would contain at most several Ra-226 luminescent gauges, resulting in a total activity that is likely less than several microcuries.

Source Term:
- Radioluminescent Ra-226 gauges installed in the instrument panel of a commercial vehicle or aircraft.

Exposure Pathways:
- External exposure, non-contact geometry.

Exposure Target:
- A commercial driver or pilot occupying the cab of the vehicle or aircraft.

Assumptions and Notes:
- In the course of their job duties, the individual occupies the cab for approximately 2000 hrs/yr.
- Gauges in the instrument panel are an average of 0.5 meters from the individual.
- The cover of the instrument panel provides no significant shielding of gamma radiation.
- Radon buildup in the cab is insignificant due to the high air exchange rate from ventilation and the opening of doors and/or windows.

Table 3 presents the scenarios and results for the dose modeling of luminescent gauges.

Table 2) Scenarios for Luminescent Gauge Dose Modeling

<table>
<tr><th>Gauge Scenario</th><th>Analogous Timepiece Scenario</th><th>Description</th><th>Summary</th><th>Exposure pathways</th><th>Assessed quantity</th><th colspan="2">Calculated Dose per µCi</th></tr>
<tr><td>1</td><td>5b</td><td>Dose due to amateur repair activities</td><td>An amateur collector attempts to repair one of their gauges. The individual handles the gauge on a workbench during the actual repair process, and stores the gauge with the remainder of their collection the remainder of the time. The entire collection is assumed to contain 50 gauges or components, with an average activity of 0.15 µCi each. The individual is assumed to sand or scrape the radium paint in an attempt to refurbish the gauge. The individual repairs up to 10 of their gauges in a year.</td><td>External exposure
Inhalation of paint
Ingestion of paint
Inhalation of radon</td><td>Total effective dose equivalent</td><td colspan="2">15 mrem/yr</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">6</td><td rowspan="2">Dose due to collecting a large number of luminescent gauges</td><td rowspan="2">An individual collects a large number of radium gauges and their components. An office occupant is 1 m away for 2000 hours/yr. Coworkers are 6 m away for 100 hrs/yr. The dose is normalized per microcurie in the collection.</td><td rowspan="2">External exposure
Inhalation of radon</td><td rowspan="2">Total effective dose equivalent</td><td>Office occupant</td><td>2.1 mrem/yr per µCi</td></tr>
<tr><td>Office coworkers</td><td>< 1 mrem/yr per µCi</td></tr>
</table>

<table>
<tr><td rowspan="2">3</td><td rowspan="2">7</td><td rowspan="2">Dose due to a catastrophic fire involving a collection of luminescent gauges</td><td rowspan="2">An individual inhales the smoke during a catastrophic fire involving the collection from Scenario 6 while trapped in the building for the entire 30 minute fire duration.</td><td rowspan="2">Inhalation of smoke</td><td rowspan="2">Committed effective dose equivalent</td><td>40 m^3 room volume</td><td>1 mrem for a 10 piece collection*</td></tr>
<tr><td>450 m^3 and larger room volumes</td><td>< 1 mrem for a 10 piece collection*</td></tr>
<tr><td>4</td><td>8</td><td>Inhalation of resuspended activity during post-fire cleanup activities</td><td>An individual spends 30 minutes cleaning up the gauges destroyed in the fire of Scenario 7, and inhales radioactive particles resuspended by the cleanup process.</td><td>Inhalation of resuspended activity</td><td>Committed effective dose equivalent</td><td colspan="2">0.5 mrem for a 10 piece collection*</td></tr>
<tr><td>5</td><td>9</td><td>Ingestion of activity during handling or cleanup of non-intact timepieces</td><td>An individual ingests radioactivity, either as they perform the cleanup activities of Scenario 8, or during other instances of handling non-intact gauges.</td><td>Ingestion of paint</td><td>Committed effective dose equivalent</td><td colspan="2">1.3 mrem for a 10 piece collection*</td></tr>
<tr><td>6</td><td>N/A</td><td>Active use in commercial vehicles or aircraft</td><td>An individual actively uses one or more gauges in a commercial vehicle or aircraft, and is exposed at a distance of 0.5 meters for 2000 hours/yr.</td><td>External exposure</td><td>Total effective dose equivalent</td><td colspan="2">6.6 mrem per microcurie in the instrument panel</td></tr>
</table>

* Note that the collection size has been reduced (from 50 to 10 items) versus the collection sizes in the timepiece report for scenarios 3, 4 and 5. This was done to consider the likely smaller size of a collection of gauges.

Conclusion

In the early 1900s, radioluminescent paint gained widespread use as a way to make various consumer products glow in the dark. The most common items to use radioluminescent paint were timepieces (watches and clocks), vehicle gauges and aircraft gauges. Beginning in the 1950s and 1960s, Ra-226 was replaced with other less hazardous radionuclides such as tritium and promethium-147. Most luminescent gauges are military in origin, although some were produced directly for civilian use. The military luminescent gauges were used in applications such as airplane altimeters and speedometers, as well as in associated tools such as voltmeters and ammeters. However, many of the military gauges have since come into public possession through such mechanisms as government surplus supplies auctions, military surplus stores, and souvenir collection stores. Current uses by the public include collection and, much more rarely, active use by installing the gauges in vehicles and aircraft.

The report *Timepiece Dose Modeling, Rev. 1* estimated doses to users and possessors of watches and clocks containing Ra-226 luminescent paint. This supplement expands upon the timepiece dose modeling to consider the dose to users and possessors of vehicle and aircraft gauges that also contain Ra-226 luminescent paint. Due to the similarity in design and construction of timepieces and gauges, the majority of the timepiece exposure scenarios are directly applicable to radioluminescent gauges under the same scenarios. This supplement evaluated one additional scenario to consider the dose to a driver or pilot of a commercial vehicle or aircraft who is exposed to an instrument panel containing Ra-226 gauges. The scenarios and results for luminescent gauges are summarized in Table 3, with results normalized to a 1 μCi Ra -226 activity.

Due to the different manufacturing and end use of gauges, Ra-226 activity content is generally higher in gauges than in timepieces. The best available source of information regarding gauge activity content is the United States military, which provided an electronic record of an inventory of Ra-226 items, including activity estimates. An evaluation of the Ra-226 activity content of gauges based on this inventory is provided in Table 1 and Figure 1 of this supplement. This information allows the dose estimates provided in this supplement to be scaled based on the desired degree of conservatism regarding gauge activity content.

References

Oak Ridge Institute for Science and Education (ORISE). Radium Timepiece Dose Modeling, Revision 1. Oak Ridge, TN; September 2007

U.S. Nuclear Regulatory Commission (NRC). NUREG-1717, Systematic Radiological Assessment of Exemptions for Source and Byproduct Materials. Washington, D.C.; June 2001.