(Copy of a study performed by a CNSC Intern, Melanie Rickard, in 2003 on the subject of radioactive contamination in waste loads. Please find attached copies of DRAFT reporting guidelines, incident reporting forms, estoppel forms, and information on monitoring systems).

Results from Studies on Radiation Alarms at Waste Management Facilities

Introduction

The number of incidents of radioactive material being identified in waste loads is increasing. This is for two reasons; the first is that increasing numbers of waste management facilities are choosing to install vehicle radiation monitors. The second, is the sensitivity of these vehicle monitors is very high and very small activities can be reliably detected. The rise in the frequency and number of incidents has made it necessary for CNSC staff to research the issue and develop a consistent approach for handling enquiries when such incidents occur.

Scope

During January and February of 2003 CNSC staff researched the issues associated with the waste alarms. Discussions with representatives from the waste management industry provided valuable information. Meetings were held with:

- Triple M Metals- a scrap metal recycler
- Miller Waster- a transfer point that ships its waste directly to Michigan, and
- BFI- a landfill near Montreal.

During these meetings CNSC staff gained an understanding of how the radiation detection systems worked, and gathered information such as the number and frequency of alarms at the site and the practices used to respond to alarms.

Additional research was gathered on the different types of vehicle radiation monitors available. This was done through web based research and through contact with product representatives. The amount and quality of information available on the different models varied depending on such things as the availability of a product representative and the amount of information available on the web page.

The information on a number of products from several manufacturers is attached as Appendix A. It provides a brief overview of product features and capabilities.

Radiation Specialists from Pennsylvania Department of Environmental Protection, Bureau of Radiation Protection were also a valuable source of information. Each landfill in Pennsylvania is

required to have a vehicle radiation monitor at the entrance. The Bureau has produced a detailed guidance document on radioactivity monitoring at solid waste processing and disposal facilities. Although the document is not entirely applicable to Canadian landfills it does contain valuable information and serves as a good reference.[1] A presentation given by a member of the Radiation Materials Section of Washington Department of Health addressed some of the issues associated with waste alarms in the US. The presentation was a valuable source of information and is referenced at the end of this document.

A presentation was given to DNSR staff in mid February that highlighted the waste alarm issue and provided preliminary milestones towards addressing the issue. Since that time additional changes and progress has been made. The conclusions and results from the work are provided below.

Conclusions and Results

It is clear to CNSC staff that each radiation alarm incident may vary greatly. Each waste management facility may have different approaches to responding to alarms and different comfort levels and capabilities of doing so. In addition, vehicle radiation monitors, while similar in principle, have different features and capabilities. Also, waste management facilities receive their waste from different sources; some are more likely to receive radioactive medical waste, for an example. Factors such as these make it difficult to recommend how the facility should deal with the waste alarms and the waste itself.

To address issues related to waste alarms three working tools have been developed. The first is a tool for reporting radiation alarm incidents. It is accompanied by recommended actions to follow when an alarm occurs. The second is an estoppel; a tool that is necessary to legally transport radioactive materials from one location to another. Finally, a bulletin to licensees of open source radioactive materials has been drafted.

Reporting Form

A generic form has been developed for the reporting of incidents involving radiation alarms by personnel at waste management facilities. The intent is that the requester will complete the form when an incident occurs and send it to a CNSC inspector. The inspector will acknowledge receipt, assess the information and respond accordingly. The information that is requested on the form will assist the inspector in determining the risk associated with the alarm. On the reverse side of the reporting form are brief recommendations of the actions to take when responding to an alarm. Due to the variety and severity of incidents that may occur, the recommendations are partially based on the dose rates measured. Once a CNSC inspector has assessed the specific information provided on the form he/she may suggest alternative actions to those provided on the form.

The incident reporting form and the guidelines are found in Appendix B.

Estoppel
Waste loads which have been identified to contain radioactive materials may be refused entry into the land fill, transfer point, scrap yard, etc. If alarms identify radioactive material in a load at the Canadian/US border, it will most likely be rejected entry into the US. In these cases, the load will have to be transported to anther location. Due to the difficulties with meeting the Transport Regulations in such instances, an estoppel has been introduced for use by CNSC inspectors. The CNSC inspector can provide the form to the requestor who will then complete the form. The CNSC inspector will review the completed form. If approved, the form will be returned to the requestor, as the carrier will require the signed document for transport.

The estoppel form is attached as Appendix C.

Bulletin
The purpose of the bulletin is to inform licensees that their waste is subject to monitoring by sensitive radiation instruments and that they must ensure they are disposing of waste within the activity concentration limits in their license.

The bulletin is attached as Appendix D.

Recommendations:

1. The recommendations for actions following a radiation alarm (Appendix B) should be reviewed by CNSC staff, particularly regarding the dose rates that are provided as a guide to action. All feedback should be directed to Bob Irwin.
2. Initially, the information bulletin may need to be reformatted as a letter and sent to all medical licensees in the Toronto area. Once the bulletin has been evaluated and approved by the Communication Services Division, it should be posted on the CNSC website.
3. The incident reporting form and estoppel should be implemented immediately. These forms should be provided to those parties who have recently requested advice from the CNSC. The forms can then be provided on a case by case basis by CNSC inspectors. Once a trial test period has passed, necessary changes should be made and the finalized forms posted on the CNSC website.
4. The list of radiation specialist consultants used by CNSC staff should be updated.
5. Determination of the dose rates from isotopes present within the CNSC disposal concentration limits in a typical waste load would be beneficial. Simplified calculations of this scenario are attached as Appendix E. However, experimental studies would be more accurate and could serve as a basis for determining the most restrictive dose rate or activity level that would trigger CNSC involvement.
6. OID Inspectors should confirm, while conducting inspections, that the licensees are properly disposing of waste and keeping accurate and complete records.

References

1. Department of Environmental Protection, Bureau of Radiation Protection and Land Recycling and Waste Management. *Final Guidance Document on Radioactivity Monitoring at Solid Waste Processing and Disposal Facilities*. Document Number: 250-3100-001.
2. Terry C. Frazee, "The use of the DOT Exemption in Washington State". BITS # 1040299.

Appendix A

Vehicle Radiation Monitors

There are a number of suppliers of vehicle radiation monitors. Most of these monitors are intended for use in scrap metal yards and land fills. The following outlines some of the main features of several types of vehicle radiation monitors. The information was gathered from manufacturer's web pages or from informal conversations and e-mails with product representatives. A selection of vehicle monitors is presented; it is not intended to represent a complete list.

1. Manufacturer: *Exploranium (www.exploranium.com)*

Exploranium's main market is the scrap metal industry, although they deal with land fills and other waste management sites as well. Exploranium is a common supplier for Canadian clients.

<u>Models</u>

The GR-500 Series

- Two scintillation detectors made of polyvinyl toluene (PVT).
- The console provides an alarm display which indicates background levels and the detected level. It also produces a loud audible alarm. An acknowledge alarm button can be depressed to stop the audio alarm. An internal printer provides a hard copy of the alarm.
- The console's graphic display runs in sleep mode until interrupted by a vehicle in the presence of the optical sensor.
- A segment counter indicates in which part of the truck the radioactive material resides.
- Alarm data is internally stored and can be retrieved to display information on the screen or the printer.
- The alarm levels vary from Level 1 to level 5, where Level 1 signals a very sensitive alarm threshold has been exceeded and Level 5 signals gross contamination and possibly dangerous radiation on all detectors in the system.
- The system is designed for 1 to 8 detectors. The most common installation uses two detectors.
- The gamma energies detectable range from 2 to 3000 keV as measured on the face of the scintillator.
- The GR-500 series includes GR-510 and GR-526.
    - Low energy threshold: GR-510:18 keV, GR-526: 2 keV

GR-606

- Similar to the GR-500 series except larger, more sensitive detectors are used.

AT-900

- Has advanced software such as a notice to personnel of the operator's response to a particular alarm.
- Sensitivity is as low as 1nSv/hr.
- Minimum operating energy level is 2 keV.
- Uses high volume PVT scintillators (6000 cubic inches).

Detectors

Single detectors come in three sizes:
- 650 cubic inches
- 1100 cubic inches
- 1500 cubic inches

The larger systems such as the GR-606 and the AT-900 have combinations of single detectors.

Sensitivity

In terms of minimal detectable activity:
- A standard detector of 650 cubic inches can detect 1.0 μCi of Cs-137 at a speed of 5km/hr at a distance of 20 inches.
- A four detector (1100 cubic inches each) fully shielded conveyor monitor can detect 0.20 μCi of Cs-137.

In terms of dose rates associated with activity:
- 650 cubic inches: 45 cps per nSv/h
- 1100 cubic inches: 75 cps per nSv/h
- 1500 cubic inches: 100 cps per nSv/h

2. Manufacturer: *ThermoEberline (www.thermo.com)*

FHT 1388 Gateway Radiation Monitoring System- used for checking cargo on trucks, rail cars and ships.
- Separate alarm settings for artificial and natural radiation.
- Features large area plastic scintillation detectors, natural background rejection, continuous background update and automatic start up.
- Uses 2 or 4 large area detectors, each 100 x 50 x 5 cm.
- Designed to function in all weather scenarios.

3. Manufacturer: *Ludlums (www.ludlums.com)*

Model 375-20RWM Waste Monitor- typically located at the scale entrance area, the system will continuously monitor incoming materials for radiation.

- Detectors consist of two each 2" diameter by 2" thick shielded NaI scintillation detectors.
- Has low level and high level alarms which are visual and audible.
- Operates in a temperature range of -29°C- 60°C.

There are many versions of this particular monitor, but they are essentially the same as the Model 375-20RWM.

Model 3500-1000RWM Waste Monitor

- The alarm can be set from 2 times background to just above background.
- The detectors are 480 cubic inch shielded plastic scintillation detectors.
- The alarm is indicated by a red flashing lamp and an audible tone. The alarm can be set internally from 4 to 34 standard deviations above background in increments of 2. A deviation setting of 30 is approximately equivalent to twice background.
- Temperature range is the same as above.

Model 3500-1000 Gate Monitor

- The system monitors background levels until the infrared sensor indicates the presence of an object. It then automatically switches to checking the object for radiation caused by contamination until the object is clear of the sensor at which time the system returns to monitoring the background.
- Alarm can be internally set from 1-8.5 deviations above background in half step increments.
- Its other features are similar to those of the 1000RWM model.

Model 3500-3000 Gate Monitor– essentially the same as the 3500-1000 Gate Monitor except they have larger detectors (two detectors, 1440 cubic inches each).

Model 3500-6000 gate Monitor- has features the same as the 3500-3000 Gate Monitor, except it has four 1440 cubic inch detectors instead of two.

4. Manufacturer: *Rados*

RTM910
Used for monitoring vehicles, packages and people for radioactive materials and contamination under all environmental conditions.

- Large plastic scintillators used for gamma detection and some neutron detection capabilities.

- Gamma energies from 60keV can be measured.
- Efficiency: Ba-133=27%, Cs-137=28%, Co-60= 52%.
- Detection limits depend on the detector configuration.

  Example: a 4 m wide vehicle passage with 4 RPD25/125 detectors: 60kBq of Co-60 at 8km/h can be reliably detected

5. Manufacturer: *Laurus Systems, Inc. (www.LaurusSystems.com)*

Vehicle Portal Monitors: VM-250 & VM-375

- VM-250- typically two self contained weather resistant pillars placed on either side of the entrance.
- VM-375- essentially the VM 250 with a third pillar positioned horizontally between the two upright pillars.
- Uses organic plastic scintillator detectors which provide approximately 17.6 litres of detector volume.
- Intended to be used where the low emissions from U-235 and Pu-29 are the main concern. Typically used in areas where detection of SNM (Special Nuclear Material) is essential, such as uranium enrichment plants, weapons manufacturing, storage plants and nuclear waste disposal plants. (Thus, not generally applicable to landfill/scrap metal sites).

6. Manufacturer: *Canberra (www.canberra.com)*

Syren 2305 & Syren 2510

- Designed to monitor movement of sources of radiation from nuclear sites, arsenals, hospitals, or at the entrances to scrap yards, incineration plants and dumps.
- Uses large plastic scintillation detectors
  - SYREN 2305: 500 x 300 x 50 mm detectors.
  - SYREN 2510: 1000 x 5000 x 50 mm detectors.
- The lower limit for detecting gamma energies is 40 keV.
- Displays in real time the status of the monitor, the background, the overall measurement and any alarms.
- Software takes into account background attenuation.
- Each monitor is equipped with audible and visual alarms and an acknowledge key.
- Response for typical background (less than 0.1 μSv/hr):
  - SYREN 2305- 300 c/s.
  - SYREN 2510- 1000c/s.
- Response for 0.1 μGy/h (^{60}Co)
  - SYREN 2305- 900 c/s.
  - SYREN 2510- 3000 c/s.

7. Manufacturer: *Rad/Comm Systems (www.radcommsystems.com)*

- PVT detectors.
- Rad/Comm has three primary sizes of radiation detector assemblies to address the applications associated with vehicle monitoring
    - RCD/1 has a PVT volume of 69.1 L. Designed for applications where the loaded vehicles scrap height can be up to 84" and the vehicle speed can be reliably controlled up to 5 km/hr.
    - RCD/2 has a PVT volume of 113.3 L for the Dual Detector assembly and 226.6L for the quad panel system. The system is designed for applications where the loaded vehicles scrap height can be up to 60" for the dual detector assembly and 120" for the Quad Panel System and the vehicle speed can be reliably controlled up to 6 mph or 10 km/hr.
    - RCD/3 has a PVT Volume of 339.9L and is intended for applications where the loaded vehicles scrap height can be up to 168" and the vehicle speed can be reliably controlled up to 10 km/hr.
- Equipped with dual infrared beam sensors which measures vehicle presence and speed.
- Sensitive to all gamma energies but uses a lower level discriminator that is typically between 10 and 30 KeV.
- The analysis is done in real time and when radioactive material is detected the system will alarm in approximately 0.5 seconds.
- The newest control console, RC401, provides counts per second and microsievert background and alarm analysis.
- Detector specifications:
    - RCD/1 will reliably detect 10 times out of 10 any sealed or unsealed source producing an exposure rate of 0.02mR/hr or 0.20μSv/hr in as surface area of 12"x12"
    - RCD/2 will reliably detect 10 times out of 10 any sealed or unsealed source producing an exposure rate of 0.015mR/hr or 0.15μSv/hr in surface area of 6"x6".

Appendix B

Incident Reporting Form for Radiation Alarms

Part A- Contact and Event Information

Name of Person Reporting	Company Represented	Job Title
Address	City	Province
Postal Code	Phone	Fax
E-mail	Date and Time of Event	
Location of Alarm Event	Origin of Shipment	

Part B- Vehicle Radiation Monitor

Make and Model of Vehicle Radiation Monitor	Sensitivity of Radiation Monitor (specify units)	
Efficiency of Radiation Monitor	Energy Range Detectable (in MeV)	
Background Reading (specify units)	Alarm Threshold of Monitor	Alarm Reading being Reported

Part C- Handheld Radiation Detector

Make and Model of Handheld Detector	Sensitivity of Handheld Detector (specify units)
Efficiency of Handheld Detector	Reading Obtained from Swipe (specify units)
Highest Reading Obtained on the Outside of the Vehicle (specify units)	Reading Obtained at 5 cm from the Source (Specify units)

Part D- Additional Details of the Incident

Description of the Item Identified to be Causing the Alarm	Identity of Radionuclide (if known)
Status of the Incident (where is the vehicle or item? What has been done? i.e, : has the item been retrieved or isolated?)	

CNSC Contact Information

CNSC Central Regional Office P.O Box 1046 Ottawa, Ontario K1P 5S9 Fax: (613) 995-5086 Tel: (613) 995-1491	CNSC Southern Ontario Regional Office 7611 Mississauga Road, Suite 794 Mississauga, Ontario, LN5 2W3 Fax: (905) 821-8544 Tel: (905) 821-7760	CNSC Western Regional Office 220-4th Avenue S.E., Suite 850 Calgary, Alberta T2G 4X3 Fax: (403) 292-6985 Tel: (403) 292-5181	CNSC Eastern Regional Office 2 Place Laval, Suite 470 Laval, Quebec H7N 5N6 Fax: (405) 668-9899 Tel: (405) 667-6360

To be filled out by CNSC inspector
Date: ……**Name:**……**Signature**……..

*** See the reverse side of this page for recommended actions to follow when responding to an alarm.**

Guidelines for Responding to Alarms from Vehicle Radiation Monitors

General:

- Solid waste management facilities (i.e., land fills, transfer points, etc.) and scrap metal facilities choosing to install radiation monitors should have procedures to follow when alarms occur.
- Arrangements should be made with a local radiation safety specialist who can provide advice.
- The vehicle alarm level should be set so that it indicates the presence of radioactive material; the general practice is to set the threshold at approximately twice background.

Actions following an alarm:

- Pass the vehicle through the radiation monitor twice to confirm a valid alarm.
- Ask the driver of the vehicle if he/she has recently received medical treatment with radioisotopes.
- Move the vehicle to an isolated area.
- Identify the origin of the shipment (i.e.- homes? hospitals?).
- Survey the vehicle with a handheld detector:
    - If the dose rates are less than 25 uSv/hr, isolate the load for several hours and re-monitor the load; the radioactive material may have decayed to values below the alarm threshold. If not, the load may be stored for longer periods until it has decayed. If possible, follow the rest of this procedure. Complete the form on the reverse side of this page and fax it to the CNSC.
    - If the rates meet or exceed 25 uSv/hr follow the rest of this procedure. Then complete the form found on the reverse side of this page and fax to the CNSC.
    - If the rates meet or exceed 100 uSv/hr create a boundary around the perimeter of the load at 10 meters. Contact the CNSC. Further instruction will be provided.
- Swipe the truck while wearing gloves and obtain a reading with a contamination monitor. If the reading obtained is approximately twice background, it is likely that the outside of the truck has been contaminated. The truck will not be permitted to travel on transportation routes until the truck is contamination free.
- If possible, an appropriately trained person should attempt to retrieve the material from the load, isolate and if possible remove the radioactive material.
- The waste should be characterized
    - If gamma spectroscopy indicates the material is from radioactive material with a half life of 65 days or less and is most likely from a patient having undergone a medical procedure, the CNSC may recommend the contents be processed or disposed of as originally intended, provided there is minimal risk to workers.

If you choose to reject the load an estoppel must be requested by the carrier. The estoppel is a tool used by the CNSC which grants permission to transport a load carrying radioactive material from one specified location to another.

Appendix C- **Estoppel**

An estoppel is a tool that may be used to ship hazardous waste when the complete Transport Regulations cannot be met. If a shipment of waste has been identified to contain radioactive materials an estoppel must be used to be move it to another location. The estoppel should be drafted by the requester; the following form is recommended. The completed estoppel request should be sent to a CNSC regional office and reviewed by staff. If the estoppel is approved, it will be sent back to the requester who will require the documentation for transport.

Part A- Contact Information

Name of Person Reporting	Company Represented	Job Title
Address	City	Province
Phone	Fax	E-mail

Name of Consignor	Company Represented	Job Title
Address	City	Province
Phone	Fax	E-mail

Name of Carrier	Company Represented	Job Title
Address	City	Province
Phone	Fax	E-mail

Part B- Details of Incident

Date and Time of Incident	Mode of Transport	Current Location of Shipment
Description of the Load	Return Destination of Load	Estimated Time and Distance for Shipment to reach Return Destination

Part C- Details of Radioactive Material and Radiation Measurements

Radiation Measurement (specify units) from the vehicle monitor producing the alarm	Background Radiation Measurement (specify units)	Efficiency of Vehicle Radiation Monitor
Is there any evidence of contamination on the outside of the truck? (i.e., has a swipe been taken?)	Dose Rate(s) Measured (specify units)	Identity of Radionuclide(s) if Determined
Any other information that may be useful		

CNSC Contact Information

☐ **CNSC Central Regional Office**
P.O Box 1046
Ottawa, Ontario K1P 5S9
Fax: (613) 995-5086
Tel: (613) 995-1491

☐ **CNSC Western Regional Office**
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Fax: (403) 292-6985
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☐ **CNSC Southern Ontario Regional Office**
6711 Mississauga Road, Suite 794
Mississauga, Ontario, LN5 2W3
Fax: (905) 821-8544
Tel: (905) 821-7760

☐ **CNSC Eastern Regional Office**
2 Place Laval, Suite 470
Laval, Quebec, H7N 5N6
Fax: (450) 668-9899
Tel: (450) 667-6360

Date	**CNSC Inspector**
Y	
M	Name……
	…… Signature
D	☐ Copy Faxed to CNSC TPLD

Appendix D

Information Bulletin

Purpose

The purpose of this information bulletin is to inform CNSC licensees that waste associated with the use of open source radioactive nuclear substances is subject to more rigorous monitoring. This is due to the increasing installation of radiation detection systems at the entrances to waste management facilities such as waste transfer points and land fills. These sensitive detectors alarm at low levels of radiation and frequent alarms are provoking questions and in some cases concern, from the workers involved.

Background

The CNSC sets activity concentration limits on radioisotopes that may be disposed of into waste streams. You are permitted to dispose of certain radioisotopes if the activity concentrations meet the limits that are set out in your CNSC licence. These limits are based on studies which show that a person will receive no more than 10 μSv effective dose in one year in a waste disposal scenario. This limit is 1/100 of the annual effective dose limit of 1 mSv for a member of the public under the CNSC Radiation Protection Regulations. Practical measurements have also been taken to validate the disposal limits.

Scope

In some instances the material which is triggering alarms at waste disposal facilities is medical waste from hospitals, clinics and homes. The CNSC recognizes that *properly* disposed of medical waste in activity concentrations within the regulatory limits may still trigger these sensitive alarms. While the CNSC ensures that regulatory limits are being followed through our inspection and licensing processes, we recommend that you review your disposal practices to ensure the concentration disposal limits provided in your license are being followed. In addition, patients who have been treated with radioisotopes and later discharged must be educated about the importance of proper disposal of related bio hazardous waste. If CNSC staff finds evidence of noncompliance with the waste disposal limits, you may be subject to CNSC enforcement actions and may be held responsible for the accumulated costs associated with the return, investigation and proper disposal of the waste.

CNSC staff has developed tools to help manage the waste alarm issues. To address the transportation issues related to the identification of radioactive materials in a waste load, an estoppel tool is being used. The estoppel is used to legally transport radioactive material from one location to another, if the Transport Regulations cannot be met. Also, a reporting form has been developed for staff at waste management facilities. They may use this form to report incidents involving the detection of radioactive materials in waste loads. The form should contain as much information about the incident and the waste load as is possible. Upon receipt of the completed form CNSC staff will assess the situation and respond accordingly. If an investigation is necessary and improper waste disposal practices by a licensee is discovered, as mentioned above, the licensee may be held accountable for any violations of their licence.

Appendix E

Estimation of Effective Dose from Radioisotopes in a Waste Load

The following is a calculation based on a simplified scenario where the dose rates from several medical isotopes are estimated. Due to the complexities associated with radioisotopes buried in a waste load, it is very difficult to confidently estimate what the dose rates would be. A comprehensive study would be necessary to substantiate the calculations presented here. This calculation provides a very crude estimation. The following assumptions were made:

- Gamma radiation is emitted from a point source.
- The gamma energy is based on the total energy from all gamma rays emitted weighted by the probability of occurrence.
- The isotope is present at CNSC disposal activity concentrations.
- The distance from the source is 1 meter.
- The isotope is shielded by 1/8 inches of steel.
- For the purposes of the attenuation coefficient, iron was used to represent steel.
- One kilogram of radioactive material is present.

Table 1: Calculation of Dose for Short Lived Medical Isotopes

Isotope	C	Γ	I_o	E	μ_m	ρ	μ_l	t	I
Ga-67	0.037	3.00E-5	1.11E-6	0.122	0.3717	7.8	2.89	0.3175	4.42E-7
Tc-99m	3.7	3.32E-5	1.23E-4	0.124	0.3717	7.8	2.89	0.3175	4.89E-5
I-131	0.037	7.65E-5	2.83E-6	0.356	0.0940	7.8	0.73	0.3175	2.24E-6
In-111	0.037	1.36E-4	5.02E-6	0.385	0.0940	7.8	0.73	0.3175	3.98E-6
Tl-201	0.037	2.37E-5	8.78E-7	0.017	25.68	7.8	200.30	0.3175	2.10E-34

A Activity of radioisotope in MBq (CNSC disposal concentration limits)[1]
Γ Specific gamma ray dose constant at 1 meter (mSv/hr per MBq at 1 meter)[2]
I_o Gamma ray intensity at zero absorber thickness (mSv/hr)
E Energy of gamma ray emission (MeV)[3]
u_l linear attenuation coefficient for *iron* (cm^{-1})
u_m mass attenuation coefficient for *iron* (cm^2/g)[4]
ρ density of steel (7.8 g/cm^3)[5]
t absorber thickness (estimated at 1/8 in. or, 0.3175 cm)
I gamma ray intensity transmitted through an absorber of thickness t (mSv/hr)

Sample Calculation:
<u>I-131</u>

$$I = I_0 \times \exp(-\mu_l t) \qquad \text{(eq.1)}$$

$$I_0 = \Gamma \times A$$

$I_0 = (7.645 \times 10^{-5}$ mSv/hr per MBq) x (0.037 MBq)
$I_0 = 2.829 \times 10^{-6}$ mSv/hr **(1)**

$\mu_l = \mu_m \times \rho$
$\mu_l = 0.0940\ cm^2/g \times 7.8 g/cm^3$

$-(\mu_l t) = -(0.7332 cm^{-1} \times 0.3175\ cm)$
$-(\mu_l t) = -0.2327$

$\exp(-\mu_l t) = \exp(-0.2327) = 0.792319$ **(2)**

Substituting (**1**) and (**2**) into equation 1 gives:
$I = I_0 \times \exp(-\mu_l t)$
$I = 2.83 \times 10^{-6}$ mSv/hr x 0.792319
$I = 2.24 \times 10^{-6}$ mSv/hr

References

1. CNSC Licence condition 2162 (rev.2)

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3. Handbook of Chemistry and Physics, 76th ed. David R. Lide, editor in chief. 1995-CRC Press, 1996. pp 11-51 to 11-121.

4. Handbook of Health Physics and Radiological Health, 3rd ed. Williams & Wilkins, 1998. p.5-11.

5. Handbook of Health Physics and Radiological Health, 3rd ed. Williams & Wilkins, 1998. p.5-50.