Operational Guidelines for Use of Radiation Portal Monitors in Nuclear Facilities

1. Introduction

Radiation Portal Monitors (RPMs) are used worldwide to scan pedestrians, vehicles, luggage, and even trains for the presence of radioactive material. RPM designers and regular users are often intimately aware of the requirements and behaviors associated with RPMs, but less so are the facility owners and operators. This presentation and associated paper is geared toward the audience of nuclear facility owners and operators who, while well versed in the traditional aspects of physical security, are less familiar with the details of testing, operating, and maintaining Radiation Portal Monitors.

A full paper will be published at a later date and be made publicly available so that all may benefit from the guidance provided herein, along with additional details and background.

2. Operation and Design

RPM operation is optimized for detection of the radiation most likely to escape from light shielding: gammas and neutrons. This is shown graphically in Figure 1.

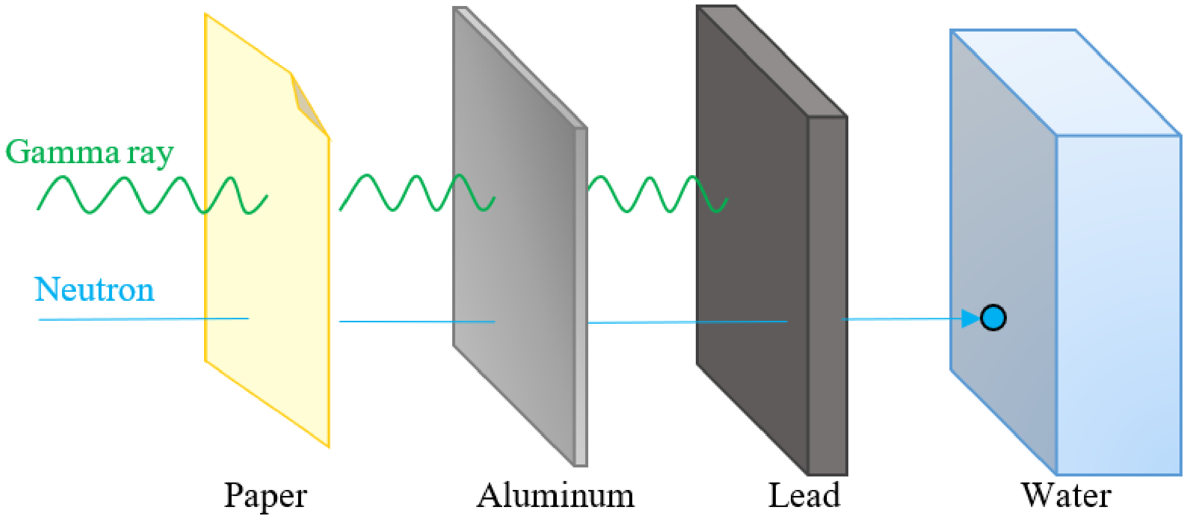

Figure 1. Radiation and its attenuation.

The electronics of an RPM are designed to detect gamma and neutron radiation, and generate an alarm when the detected level of radiation exceeds a pre-determined threshold:

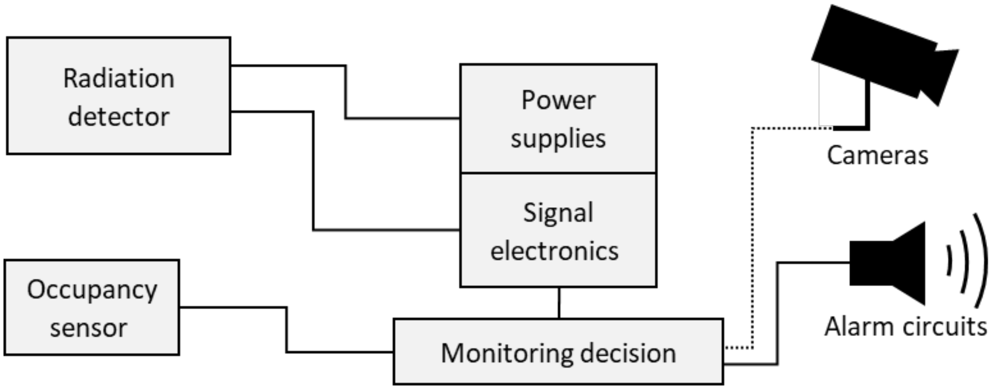

Figure 2. RPM electronics layout.

3. Gamma Detection

RPMs typically use one of three types of detectors, as described in the below table.

Table 1. Typical RPM gamma detection methods and their tradeoffs

	Plastic scintillator	**NaI scintillator**	**High-purity germanium**
Advantages	Plastic scintillators are relatively cheap and rugged and can be formed into large rectangles to provide a large detector area.	NaI is the most common detector material for spectroscopic purposes because it is relatively affordable (although more expensive than plastic) and available in sizes up to 10 cm wide × 10 cm thick × 40 cm long.	High-purity germanium is the gold standard for identification; the sharp peaks make identification simple and conclusive.
Disadvantages	Plastic scintillators have poor energy resolution, which requires advanced algorithms to distinguish uranium from plutonium from other sources.	The algorithm that identifies radioactive materials must be tested for accuracy because operators will be trusting the results of the identification algorithm to allow an occupancy to proceed. Additionally, the need for a proper calibration is more acute with a spectroscopic system.	This is the most expensive detector material. Crystals can cost $100,000 each, and four to eight crystals are required to scan a large vehicle. High-purity germanium must be kept at very cold temperatures (−200°C), which require constant electricity and can be prone to failure.
Comments	Plastic is a good choice when the RPM occupancies are not expected to have many sources of NORM. Most nuclear facilities rarely see these types of NORM-bearing commodities entering or exiting the facility.	NaI is commonly used in handheld radiation detectors, often to help resolve alarms generated by plastic-based RPMs. A NaI-based RPM is useful in a stream of commerce in which there is a high distribution of NORM cargo, and the time or cost of resolving RPM alarms using handheld means would be prohibitive.	This is required for very complicated spectra such as mixed waste.

4. Neutron Detection

Few forms of nuclear material are intense neutrons emitters; neutron emitting sources are rare in the stream of commerce. Although neutron detectors can be expensive, neutron radiation is very penetrating and thus is practical for scanning vehicles.

Helium-3, or ^{3}He. It is the most common type of neutron detection material. It is rugged, dependable, low maintenance, and has good sensitivity. In the early 2010s, a global ^{3}He shortage made ^{3}He-based neutron detection almost prohibitively expensive; however, since that time, ^{3}He has become more available, and prices have dropped.

Four ^{3}He tubes, each 5 cm in diameter and 91 cm length, pressurized to 2 atm, provide sufficient sensitivity for most vehicle RPM applications; however, the owner must determine what neutron sensitivity is required for their facility.

Lithium. Lithium–zinc–sulfide and other lithium-based detection systems developed in response to the aforementioned ^{3}He shortage and now provide a cost competitive alternative to ^{3}He-based systems. Lithium-6 has a relatively large cross section for neutron absorption and can be placed in other materials (glass, fibers, sheets) that take advantage of its neutron-absorbing capabilities to provide indications of a detection. Some forms come in sheets or slabs, and others come as drop-in replacements for ^{3}He tubes.

5. Specifying Performance

When specifying the detection requirements of an RPM, it is important to specify completely the conditions under which the detection must happen: the background level, the speed of the conveyance moving through the RPM, the spacing between pillars of the RPM, any shielding associated with the occupancy (including shielding that may be inherent in the vehicle, such as the vehicle frame or engine block, if credible), the source intensity (including details like item form [metal or oxide], enrichment, shape, and density), and the acceptable statistical false alarm rate at which the detection must occur. A purely hypothetical example is as follows:

> The RPM shall provide a 50% alarm probability or higher on a sphere of metallic uranium enriched to 90% ^{235}U weighing 1 kg when placed in the centerline in the bed of a standard pickup truck traveling through the portal at 8 km/h in a radiation background of 150 nSv/h or higher. Spacing between the faces of the pillars shall be 4.2 m or greater. The RPM shall produce fewer than 1 false alarm in 1,000 occupancies generated by artificially blocking the occupancy sensors for 4 s, with 10 s between occupancies.

Additional examples are provided in the references.

6. Factory Acceptance Test/Receipt Inspection

Sensitivity Testing

Some experimental testing should be conducted to determine the least sensitive region of the RPM, and the most shielded location associated with the conveyance. It is important to test the RPM under the most challenging conditions, not the most likely or the most favorable conditions.

Table 2 below shows the number of successful test runs that must be conducted to demonstrate 95% confidence of the desired detection probability.

Table 2. Number of trials and successes required to demonstrate the desired probability of detection using a 95% one-sided confidence interval calculated using the Wilson confidence intervals

No. Trials	**Number of detections required to demonstrate a probability of detection (95% confidence interval)**				
	0.5	**0.7**	**0.8**	**0.9**	**0.95**
10	8	10	—	—	—
20	14	18	19	—	—
30	20	26	28	30	—
50	31	41	45	49	—
60	37	48	54	58	60
100	59	78	87	95	99

Note that, if a 50% probability of detection can be acceptable (from a suitably *small* source), then the test requirements become considerably easier. It is logistically more feasible to run a test and record eight out of ten trials, or 14 out of 20 trials, than it is to conduct 100 trials with 99 successes, if a detection probability of 0.95 is desired.

False alarm testing

False alarm testing is critical after the sensitivity testing has been completed. Sensitivity testing is usually conducted first because it is easier to adjust settings if necessary and re-test; the statistical false alarm testing is run afterwards as a confirmatory measurement.

Typical values for a statistical, Gaussian-based algorithm are described in Table 3.

Table 3. Expected false alarm rate according to n.

n	**Average false alarm rate**
0	1 every 2 walk-through
1	1 every 6 walk-throughs
2	1 every 44 walk-throughs
3	1 every 741 walk-throughs
4	1 every 31 574 walk-throughs
5	1 every 3 488 556 walk-throughs

Fault Testing

RPMs can usually provide indication that something is operating incorrectly; this fault generation must be tested because it will be relied on during operation. Common faults and their test methods are described in Table 4.

Table 4. Common fault conditions and tests examples

Fault	Object	Test
Background too high	Detect artificial increase of the background	Without triggering an occupancy, gradually move a radioactive source toward the detection zone until the fault is generated
Background too low	Detect sensitivity degradation caused by potential detector malfunction	Set the fault level to an abnormally high value and wait until natural background fluctuations dip below that level
Nonresponsive occupancy sensor	Detect degradation of the occupancy sensor	Unplug/disconnect the occupancy sensor at the RPM and see if a fault is generated
Tamper indication or cabinet door open	Detect intrusion	Open cabinet door; confirm alert at the CAS
Communication failure	Detect electronic or cyber-aggression of the communication between the RPM and the control station	Disconnect the RPM from the CAS and observe the response on the CAS

7. Operational Testing

Operational testing should be conducted either daily (e.g., at the start of each shift to confirm proper operation), or annually, to ensure that the long-term performance of the RPM is being maintained.

Daily testing consists of a brief sensitivity test with a source that is expected to generate an alarm, then an occupancy sensor check to ensure that an occupancy is generated when expected (failure to generate an occupancy can result in a false negative that may not be readily apparent to operators), then a communications test to confirm that the data is properly recorded at the Central Alarm Station, a review of any Faults that may be indicated at the Central Alarm Station, and finally a brief check of the important RPM settings.

Annual testing consists of a rust check and/or cleaning (corrosion can severely limit the lifetime of RPMs, particularly those operated outdoors), a battery health check if the RPM has a battery backup, a calibration check to make sure the energy alignment has not drifted, and, if necessary, a more detailed sensitivity check with multiple runs to ensure that the detection sensitivity is consistent with that determined when the system was initially accepted.

8. Sample Forms

RPM Evaluation Data Form

Name: ____________________ Date: _________ Location: ______________________

RPM INFORMATION

Manufacturer: ______________ Serial #: ________ RPM type: ____________________

Setting 1 name: ____________ Value: _______ Setting 3 name: ____________ Value: _______

Setting 2 name: ____________ Value: _______ Setting 4 name: ____________ Value: _______

(Include more settings on back if necessary.)

Background reading: __________________ Background duration: _________________________

SENSITIVITY TESTING:

Source used: ________________________ Source location: ______________________________

Description of source strength (e.g., grams, µSv, Bq): ______________________________________

Number of trials: _____________________ Number of detections: _________________________

Result (circle one): PASS FAIL

FALSE ALARM TESTING:

Occupancies generated by (e.g., empty vehicle, hand, electronic): ______________________________

Number of trials: _____________________ Number of false alarms: _______________________

Result (circle one): PASS FAIL

RPM Daily Test Form

Name: ____________________ Date: _________ Location: ______________________

RPM serial #: ________ RPM type: __________ Source used: ____________________

Count rate: ______________ In agreement with the reference count rate: YES NO

Occupancy recorded at CAS: YES NO Alarm generated: YES NO

(If either of the above answers is “NO,” contact maintenance immediately and implement compensatory measures.)

Faults on CAS: YES NO If yes, explain: ____

9. References

References to aid in the operation of RPMs in nuclear facilities exist, but are distributed across many older sources and can be difficult for the inexperienced to know about or discover via usual search methods. The following is a listing of the most valuable / accessible references.

IAEA Nuclear Security Series No. 13, Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities, INFCIRC/225/Revision 5, 2011. DOI: 10.61092/iaea.ko2c-dc4q

York, R. L., and Fehlau, P.E., *1997 Update for the Applications Guide to Vehicle SNM Monitors.* LA-13247-MS. DOI: 10.2172/468602

- ASTM International, Standard Guide for Application of Radiation Monitors to the Control and Physical Security of Special Nuclear Material, C1112-99(2005), withdrawn in 2014.
- ASTM International, Standard Guide for In-Plant Performance Evaluation of Automatic Pedestrian SNM Monitors, C1169-97(2012), withdrawn in 2021.
- ASTM International, Standard Guide for In-Plant Performance Evaluation of Automatic Vehicle SNM Monitors, C1236-99(2005), withdrawn in 2014.

The above three references have been withdrawn for unknown reasons, but the authors still find the content valuable and accurate.

International Electrotechnical Commission, Radiation protection instrumentation - Installed radiation portal monitors (RPMs) for the detection of illicit trafficking of radioactive and nuclear materials, IEC 62244:2019.

Defining the Test Source

The *1997 Update for the Applications Guide to Vehicle SNM Monitors* (available at https://www.osti.gov/biblio/468602) lists 10 g of low-burnup plutonium or 1,000 g of highly enriched uranium as worst-case detection sensitivities. Note that the material type, geometry, vehicle speed, background, and object placement are all carefully specified because these can significantly affect RPM performance.

Rather than describing a source and test conditions, the *Technical Capability Standard for Radiation Portal Monitor Systems with Energy Analysis Capability* (available from https://www.dhs.gov/sites/default/files/publications/radiation-portal-nseac-tcs-11-2019.pdf) lists the fluence rate of the source at the detector assembly. This is the number of gamma rays that impinge upon the detector face per square centimeter per second. Testing using this method is less prescriptive for the source and shielding, but it requires additional analysis on the part of the testers to provide the correct test conditions.

RPM Life Cycle Maintenance

In 2001, the US Department of Energy (DOE) issued the Nuclear Facility Maintenance Management Program Guide for Use with DOE Order 433.1. It is available here: https://www.directives.doe.gov/directives-documents/400-series/0433.1-EGuide-1/. Later versions have updated, modified, and simplified in this document, but the authors believe this 2001 version provides the best, most detailed guide to maintaining equipment in a nuclear facility.