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LESSON 12:

WORKPLACE MONITORING IN OPERATING NUCLEAR REACTORS

Impact of Reactor Type

- Impact of reactor type, age and plant state.
- Fingerprinting.
- Operating reactor monitoring and challenges.
- Specific examples.
- Does not address nuclear emergency monitoring.

Impact of Reactor Type

- Different reactor types may present unique challenges:
  - Pressurized water reactors
    - The most common type of reactors neutron flux during power operation, corrosion products, steam generator.
  - Heavy water cooled reactors
    - High concentrations of tritium from heavy water moderator – can be hundreds of DACs in the workplace and thousands of DACs from a small spill of moderator water.
  - Boiling Water Reactors
    - Contamination can be found in turbine plant components due to design.

Impact of Reactor Age

Older reactors may have had historic fuel integrity challenges potentially resulting in:

1

Legacy of hot particles or discrete particles dispersed in the plant.

2

Alpha contamination embedded in primary systems from failed fuel (which may or may not be detected by wipes, and may be shielded by subsequent deposits.

3

Excessive contamination with radioactive corrosion products due to wrong choice of materials used in primary system components.

Impact of Plant Site

- In light water reactors, prompt activation of oxygen in the coolant water systems results in the production of N-16, a short half life, very high energy gamma emitter which contributes to very high dose rates at power in the primary system.
- In BWRs, there can be carry over of ^{16}N to the steam side resulting in sky shine which can impact other areas.
- N-16 has a very short half life and decays rapidly after shutdown reducing the external dose rate in the primary system.
- Neutrons are present at power and not upon shut down.
- May be increase in dose rates following crud burst following shutdown.

Radiation Fields

- Gamma radiation fields due to:
  - Activation of reactor systems and components.
  - Activation and deposition of contaminants in primary systems.
  - Contamination in primary systems from fissions products.

- Gamma radiation fields from a mix of radionuclides typically dominated by easily detectable radionuclides, such as;
  - Corrosion products: Co-60, Mn-54.
  - Fission products: Cs-137.

Image from Gamma Camera

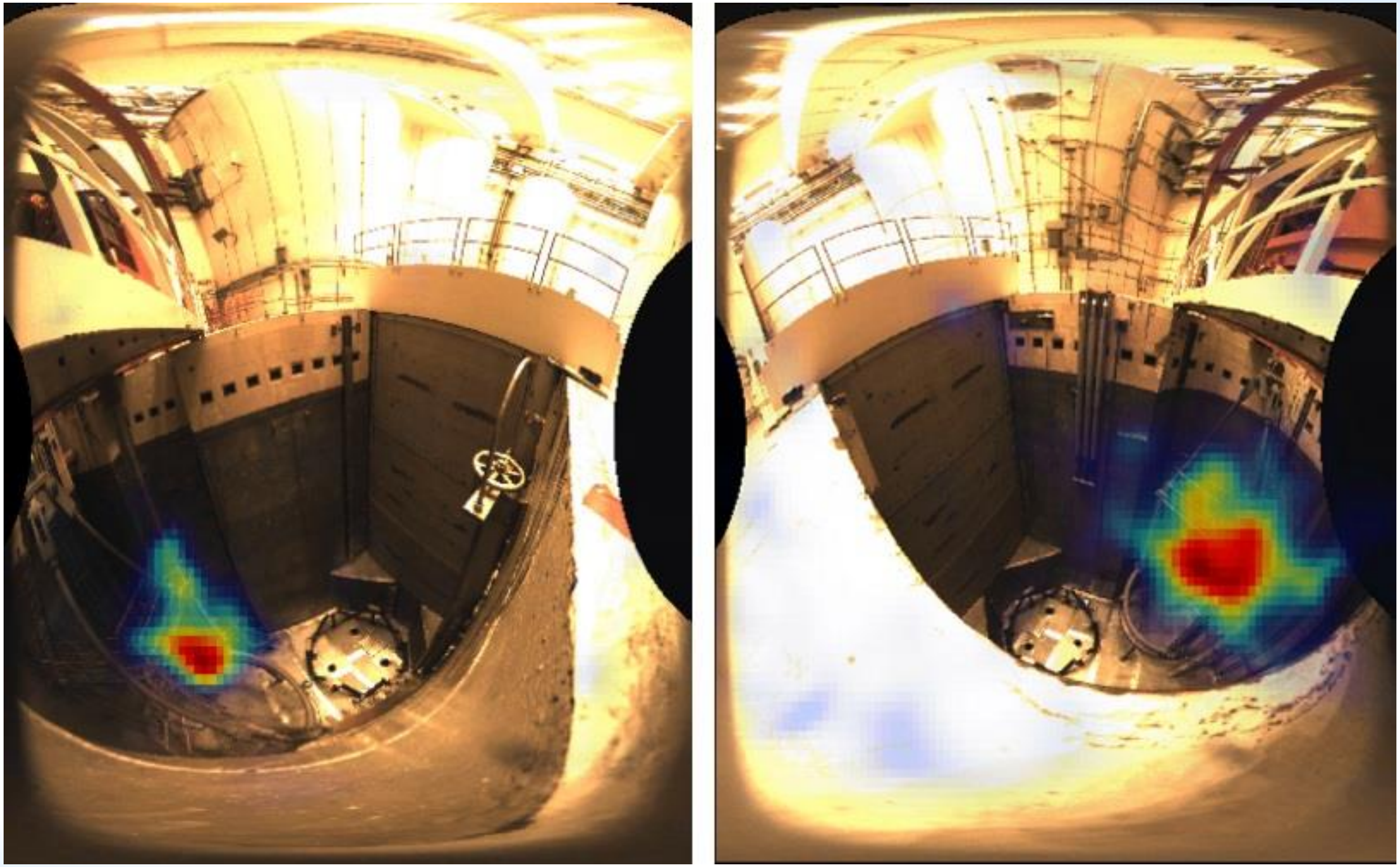

Image of dose rates using CZT

Contamination Fingerprint

Contamination should be characterized

- To identify beta and possible alpha emitters to ensure accounting for internal dose properly.

Characterization should use gamma spectrometry and radiochemical analysis of samples taken from throughout the plant systems to identify:

- The radionuclide mix in typical contaminants (scaling factor methodology is often used in waste handling)
- The contribution to internal dose from radionuclides not typically detected by contamination monitors such as Fe-55, C-14
- The possible alpha emitters in the contamination.

Typical Contaminants

Contamination could contain a range of fission and activation products.

- Generally moderate energy beta emitters present and contribute most to internal dose – Sr-90, Cs-137, Co-60.

- Mix of beta/gamma emitters can be detected by:

1. beta/gamma dose rate meters, in case of high levels of contamination (μSv/h to mSv/h).
2. most beta contamination monitors, in case of moderate levels of contamination (tens to hundreds of Bq/cm²).
3. thin window GM tubes, in case of low levels of contamination (range of reference levels, Bq/cm²).

Some Contaminants are not easy to detect

- Some contamination due to low energy beta and low energy X or gamma e.g. H-3, C-14, Fe-55, typically not contributing significantly to dose
  - Specific WPM is not usually necessary, once their contribution to dose has been identified.
- Alpha contamination could contribute significantly to internal dose;
  - Typically is limited to the primary circuits, steam generators, but also removed primary system components in storage, and waste areas.
  - Determining beta/gamma to alpha ratios can be a useful method to identify radiological significance.
    - At 3000:1, approximately 50% of inhalation dose will be from alpha and 50% from beta/gamma.
  - The need for monitoring of alpha contamination and airborne activity is determined by the presence of alpha activity and the ratio of beta gamma to alpha activity.

Specific Radionuclides

- Radionuclides which might be additionally released, especially for failed fuel elements:
  - Noble gases
    - Krypton, Xenon.
    - These short half life gases can result in widespread contamination.
  - Iodine
    - Wide range of short half life radioisotopes.
- Tritium
  - Common in CANDU reactors.
  - Not usually significant quantities in other reactor types.

Typical WPM in an Operating Reactor

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Routine Monitoring

-Contamination, radiation dose rate for classification of areas.

-Verification of permissible levels or clearance levels.

Task Monitoring

-Monitoring to ensure doses are ALARA, either in advance of or during work.

Special Monitoring

-Investigations to identify where shielding should be placed.

-Investigations following incidents.

Typical WPM in an Operating Reactor

Full range of monitoring requirements:

- Radiation dose rates
  - Gamma, beta and neutron
- Radioactive contamination
  - Beta, gamma, alpha in some cases
- Airborne radioactivity
  - Beta airborne activity is common, with a possibility of alpha.
  - Radioactive iodine isotopes.
  - Noble gases.
  - H-3 and C-14 (in some applications).

Installed WPM Equipment

- Range of installed gamma and neutron monitors will be provided throughout the operating reactor to:
  - Identify abnormal conditions, e.g.in the reactor or lowering of water level in the spent fuel pool
  - Measure ambient radiation dose rates.

- Results are usually relayed to the control room

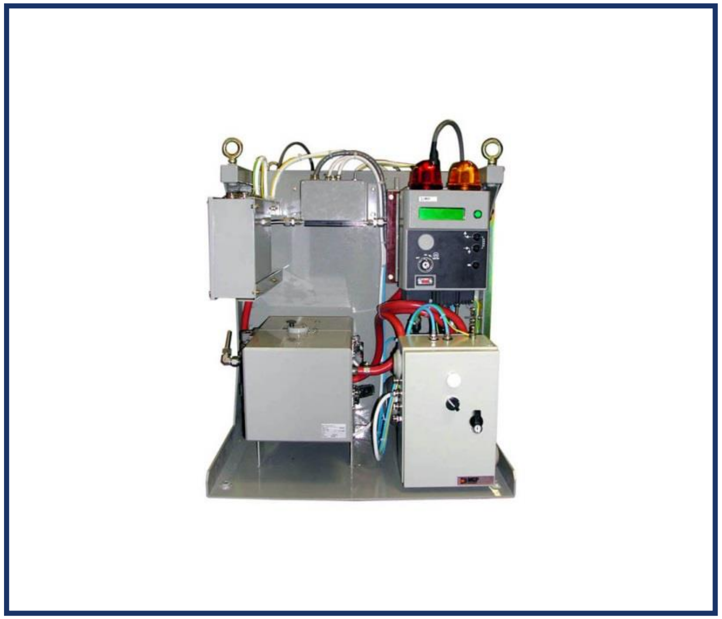
- Continuous monitoring for iodine, noble gases and particulates is typical to identify abnormal conditions, e.g. failed fuel, incident .

- WPM equipment should be a part of the plant design.

Area WPM Equipment

- Installed WPM equipment, with alarm settings, for continuous area monitoring of
  - Gamma dose rate
  - Beta particulate airborne activity
  - In specific reactors and applications
    - Airborne tritium monitors (heavy water reactors)
    - Airborne alpha monitors
- Portable area monitors are used for specific tasks, e.g. outage re-fuelling and maintenance work.

WPM Equipment



Continuous air monitor

Area gamma monitor

Courtesy: Nucleonix

Portable Monitors – Gamma Dose Rate

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Wide range of gamma dose rates:

- Dose rate monitoring for transport
  - Low dose rates – down to μSv/h
- Dose rates during routine operations and outages, and to reduce doses ALARA.
  - Typically 5 μSv/h - 50 mSv/h
- Very high dose rates during power operation in some non-accessible parts of the plant.
  - Up to several Sv/h
    - Need to have range capability to measure these.

Other Examples of Dose Rate Monitoring

- Uniform gamma fields from wide beams e.g. around reactor system components or in a waste storage facility.
- Narrow beams, e.g. from shielding weaknesses.
- Other sources such as waste drums and pipework (could be visible, overhead or underground).
- Hot spots of contamination trapped in systems, components or on surfaces, which can be point sources.
- Dose rates underwater in spent fuel pools, which may require underwater dose rate monitoring equipment.
- Neutron dose rates through leakage paths at power (streaming).

Contact Gamma Dose Rates

Gamma dose rates measured on closed reactor systems to identify:

- Sources of radiation to avoid exposure.
- Temporary shielding requirements prior to maintenance work .
- To check dose rates with shielding.
- Sources to be removed, e.g. hot spots.

Gamma dose rates in open reactor systems or inside spent fuel pools (for diving operations).

Other Types of Contact Dose Rate Measurement

Contact beta/gamma dose rate from open systems during outages.

- Unshielded debris may have high contact dose rates (e.g. after cavity drain-down).
- High beta and gamma dose rates from fuel fragments or contamination following a recent fuel failure.

Contact beta/gamma dose rates from underwater sources (debris/fuel fragments) in spent fuel pools.

Contact beta/gamma dose rates from sealed sources used for testing and calibration.

Portable Dose Rate Measuring Equipment

Ionization chamber

Gamma identifier-Scintillator

Teletector-GM

Gamma spectrometry kit

Neutron

Specific Radiation Monitoring Challenges

- Remote gamma dose rate monitoring
- Measuring beta dose rates
- Protecting equipment from contamination
- Underwater gamma dose rate monitoring

Remote Monitoring Examples

Contamination WPM

Equipment to detect contamination of moderate and high energy beta/gamma:

Beta/gamma radiation dose rate monitors for high levels of contamination.

↓

Plastic scintillators, proportional counters and standard GM probes for moderate levels of contamination.

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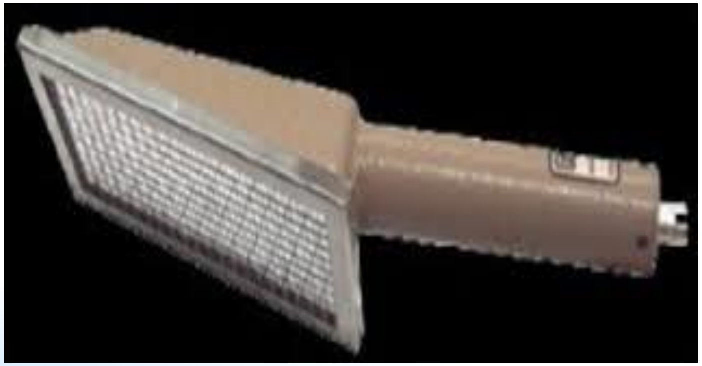
Proportional or scintillation counters for low levels of contamination, typically for clearance.

Equipment for Contamination

GM detector

Thermoscientific SmartIon

Pancake detector



Alpha Scintillation counter

BF_3 counter

Monitoring Challenges

1. Background gamma radiation in and around reactor systems inside containment can prevent the direct monitoring of beta/gamma contamination, e.g. during re-fuelling and maintenance outages.
2. Direct contamination monitoring can be conducted where dose rates are lower, e.g. outside of containment and for release of materials from contaminated areas.
3. Hot particles should be detected as soon as possible
4. Beta emitting particles can be easily shielded, therefore not readily detected.

Indirect Contamination Monitoring Techniques

- Variety of techniques are used to measure non-fixed radioactive contamination.
  - Dose rate scanning for hot particles (e.g. fuel fragments or activated stellite).
  - Large area wipes monitored by a beta/gamma contamination meter or dose rate meter to measure contamination levels or confirm absence of non-fixed contamination.
  - Small area wipes monitored by beta/gamma contamination meter or dose rate meter to quantify contamination levels.
  - Wipes may also be monitored for alpha contamination.
  - Small area wipes may be measured using counting equipment if the activity is low enough to avoid contaminating the equipment.

Indirect Contamination Monitoring Techniques

- Large and small area wipes used on:
  - Components and surfaces, especially floors:
    - Before work to check the levels of non-fixed contamination.
    - During the work to check the level and spread of contamination.
    - After work to confirm the absence of non-fixed contamination.
  - Prior to shipment, the outside surface of packages to confirm the absence of non-fixed contamination and then to quantify for transport documentation.
  - Tools and equipment to confirm the absence of non-fixed contamination prior to leaving the controlled area.
- Direct monitoring can be conducted wherever background radiation levels permit.

Indirect Contamination Monitoring Techniques

Mop wipes used for cleaning and decontamination of large areas can be measured for contamination.

Sticky mats/rollers can be used to capture and measure particulates.

Small items gamma monitors can be used to identify contamination on e.g. tools and equipment.

Examples of Indirect Contamination Monitoring

Examples of taking wipe samples

Sticky mat

Monitor to measure wipes

Contamination Monitoring

Alpha contamination probes and counting equipment may be required.

- As alpha contamination measurement is not often conducted in operating nuclear plants, it can be challenging to develop and maintain expertise.

Gamma spectrometry capability for radionuclide identification of detected contaminants.

- To identify source of contamination.
- To determine dosimetry implications.

Alpha spectrometry required for identification of alpha contaminants.

- Usually not an onsite capability.

Gamma Spectrometer

Airborne Contamination Monitoring

- Beta/gamma monitoring in air.
  - Medium to high volume installed air samplers used for routine operation
  - Small volume air samplers used during specific tasks and/or in specific areas (relatively high DACs easily detected).
  - Air samples can be screened using portable contamination monitor for immediate indication of contamination.
  - May perform particle sizing in special circumstances.
- Alpha monitoring requires larger volumes of air and the use of a scaler to measure fractions of DAC values.
- Radon daughter interference was discussed in lesson 6
  - May use discriminating counters.

Exampled of Particulate Air Sample Monitoring

Portable particulate monitor

Counting equipment examples

Air Sample papers – clean and used

Airborne Contamination

Recent fuel failures may give rise to the release of noble gases and iodine radioisotopes upon shutdown (and which require additional workplace monitoring including:

- additional monitoring of widespread contamination from noble gases.
- iodine monitoring.
- alpha monitoring (note this could also remain embedded in systems in future).

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Airborne Tritium Monitoring

Tritium can easily spread and disperse from irradiated heavy water spills and wetted materials.

- Portable H-3 detectors and passive samplers are used during work with liquids to identify tritium in the workplace.
- Installed H-3 monitors are used to measure ambient H-3 levels and detect abnormal conditions.

Installed H-3 monitor

Hand held H-3 monitors

Summary

- Impact of reactor age, type, plant condition.
- Fingerprint (hard to detects, alpha, specific radionuclides).
- Installed gamma and airborne monitors.
- Range of portable monitoring equipment for radiation dose rates, contamination, air activity .
  - challenges include background radiation, hot particle, shielded beta particles, remote monitoring.
- Gamma spectrometry widely used.
- Beta gamma airborne monitoring.
- Noble gases, iodine, alpha and H-3 when required.