Lesson 3: Core Damage and Release Assessment

Lesson Overview

The purpose of this lesson is to provide an overview of core damage and release assessment, as they relate to the complexity of monitoring release.

Upon completion of this lesson, you will be able to:

- Identify the indicators of core damage.
- Describe the two types of releases.
- Explain why an accurate computer modeling of a release is difficult.

Remember you can access the glossary in one of two ways throughout this course. You can select the glossary button in the top right hand corner of each main content screen. In addition, on content screens you can select underlined words to access their definitions in the online glossary. Selecting an underlined word will take you directly to its definition in the glossary.

This lesson should take approximately **35 minutes** to complete.

Types of Assessments

There are two types of assessments:

- Core damage assessment
- Release assessment

In the next section of this lesson, you will learn about core damage assessment as well as the indicators of core damage.

Indicators of Core Damage (1 of 2)

Indicators of core damage include the following:

- A critical safety function is lost.
- The cooling capabilities are impaired.
- Pressurized water reactor (PWR) core exit thermocouples indicate high temperatures.
- Water level is below the top of the core.
- Containment monitors show elevated radiation readings.
- Coolant or containment air samples show high activity.

Indicators of Core Damage (2 of 2)

There are key indicators that predict or indicate core damage.

- Safety Function Status:
  - predicts core damage
- Water injection:

    - predicts core damage
- Water level:
    - indicates imminent core damage
    - not measured in many PWRs
    - measured BWRs
- PWR core temperature
    - Indicates imminent core damage
    - Measured in PWRs
    - Not measured in BWRs
- Radiation levels:
    - confirm core damage

Note that some of the indicators are measured in PWRs only and others in boiling water reactors (BWRs) only.

Progression of an Incident

Now that you have learned about indicators of core damage, you will find out how an accident can progress from failure to atmospheric release.

Three Mile Island Unit 2 (TMI-2) Accident: Introduction

In the next few screens you will learn about the accident at Three Mile Island Unit 2 (TMI-2) nuclear power plant and how this accident is an example of core damage assessment.

TMI-2: Instruments

Instruments showed radiation levels in the plant at TMI. Within the first hour of the accident, numerous indicators of core damage went unrecognized.

Remember that radiation levels will increase in plant after core damage.

Officials did not know how instruments would act under accident conditions. Their confusion resulted in problems such as the following:

- Samples were not representative.
- Instruments were not read correctly.
- Instruments were not calibrated correctly.

TMI-2: Core Damage Indicators

Officials did not see the "big picture" or recognize the emerging pattern. Many things were going wrong simultaneously and, in general, readings were going up. Officials should have realized that the reactor was failing, but they did not.

Clear indicators of core damage were:

- Containment monitor radiation readings of 6,000 R/hr

- Core exit thermocouple temperature of 2,000° F (cladding failure at 1,200° F)

Instruments can be confusing during accidents. Therefore, never use a single instrument as a basis for assessment.

TMI-2: Core Damage

Within an hour, numerous process monitors were rising by factors of ten. Officials should have realized that core damage had occurred, but were confused by instrumentation problems noted earlier.

Officials did not realize they had melted material, between 20 and 40 tons, at the bottom of the containment vessel. After they realized the core was uncovered, they re-covered this material with water.

TMI-2 Conclusions

The Presidential Commission looking into the TMI accident found that:

- There was an incredible amount of radioactivity inside the containment.
- Plant authorities did not know what was happening.
- Plant authorities took no protective action.
- Under current criteria, people would be evacuated between five and ten miles around the plant.
- Many residents living around the plant voluntarily evacuated in an orderly manner.

Fukushima Nuclear Incident: Introduction

Now that you have learned about the Three Mile Island incident, you will find out what happened during the Fukushima nuclear incident.

The Tohoku earthquake, which occurred on Friday, March 11, 2011 on the east coast of northern Japan, is believed to be one of the largest earthquakes in recorded history, and the largest earthquake ever recorded in Japan. The earthquake and following tsunami resulted in over 19,000 deaths, inundated about 560 square kilometers, and caused $500 billion or more in damage and economic loss in Japan.

Fukushima Nuclear Incident: Progression of Events

Fifteen nuclear power reactors at five sites were in the area affected by the earthquake and tsunami. Eleven of these reactors were operating at the time of the earthquake, ten of them at full power. All of the operating reactors shut down automatically in response to the seismic activity. The earthquake and following tsunami caused disruption to all 15 reactors, ranging from partial loss of off-site power to complete loss of off-site and on-site power. The most severely affected plants were those at Fukushima Daiichi and Fukushima Daini.

Release Assessment

In the next section of this lesson you will learn about release assessment and what the incidents at Chernobyl and Fukushima have taught us about how to conduct this type of assessment.

Estimating the release rate and time is important, because they are the basis for dose projection. In order to calculate a dose to a population, parameters such as estimated release rate and duration are necessary. If the rates are unknown, calculations should be made using the upper and lower bounds of the range of possibilities.

Let's explore the two types of release characteristics:

- Unpredictability
- Unusual characteristics

Unpredictability (1 of 3)

The source term is an estimate of the composition, rate, timing, and elevation of a release from a nuclear power plant.

Accurately estimating the source term is difficult because:

- It is difficult to estimate the release characteristics – composition (isotopic mixture), rate (Ci/s or Bq/s), time release will begin, and elevation.
- There are very large uncertainties, especially with severe accidents.

Unpredictability (2 of 3)

There are two types of releases:

- Monitored releases
- Unmonitored releases

Unpredictability (3 of 3)

The Nuclear Regulatory Commission (NRC) has expended large amounts of money and effort to assess both what is released during an accident and where it will go. The accuracy of estimates remains questionable because of the large number of variables involved.

It is necessary to verify projections using actual environmental measurements. These measurements will dictate whether additional protective actions need to be taken.

Unusual Characteristics

In the event of a major release, the usual characteristics of a release should be considered:

- Timing
  - 30 minutes to 24 hours after core damage
  - Last hours to days
- Rate profile
  - Very rapid at first, slowing down, and continuing for a long time

    - Small release whenever the core is damaged
- Ground-level release

At TMI, the core was severely damaged, but the containment held. The TMI release was very rapid at first, then tapered off.

Release Assessments: Chernobyl (1 of 3)

Next you will learn about what the Chernobyl accident taught us about conducting release assessments.

On April 26, 1986, an accident occurred at Unit 4 of the nuclear power station at Chernobyl, Ukraine, in the former USSR. The accident, caused by a sudden surge of power, destroyed the reactor and released massive amounts of radioactive material into the environment.

Release Assessments: Chernobyl (2 of 3)

On the first day of the accident, the release was 12 megacuries. For the next five days, the amount released decreased; then levels began to rise again.

Estimates of radionuclide released include: about 3–4% of the used fuel in the reactor at the time of the accident, 100% of noble gases and 20–60% of the volatile radionuclides were released. The radionuclide mix was complex. Iodine isotopes had the greatest short-term impact while cesium isotopes had the greatest long-term impact.

The food monitoring results from the Food and Drug Administration (FDA) and others following the Chernobyl accident support the conclusion that I-131, Cs-134, and Cs-137 are the principal radionuclides that contribute to radiation dose by ingestion following a nuclear reactor accident, but that Ru-103 and Ru-106 also should be included.

Release Assessments: Chernobyl (3 of 3)

The Chernobyl accident also provided some important historical data:

- The reactor failure resulted in an upward explosion (not a ground level release) causing dispersion over a very wide area. Much of the airborne radioactivity was driven into the stratosphere and upper atmosphere. This accounts for the relatively small number of deterministic health effects resulting from the accident.
- The mix of the release changed over time with wind direction.
- The plume was affected by the wind.
- Several hundred kilometers away, there were pockets of higher radiation from material deposited by rainout.

Next, you will learn about what the Fukushima incident taught us about conducting release assessments.

Release Assessments: Fukushima (1 of 2)

There have been no deaths or cases of radiation sickness resulting from the nuclear plant destruction precipitated by the regional disaster of March 11, 2011. However, as a result of the severe damage to station reactors and the subsequent radioactive material releases, more than 100,000 people were evacuated from their homes. Due to the dispersal of radioactive material across the regional environs, monitoring of the affected region, emergency workers, and members of the public will continue for many years.

The standard dose limit for radiation workers in Japan is 50 milli-sievert per year (mSv/yr) with a limit of 100 mSv over a 5-year period. As a result of the magnitude of this event, the emergency dose limit in Japan was raised to 250 mSv/year (25 rem/year) due to the seriousness of this accident. During the course of accident mitigation efforts, six workers received doses exceeding the emergency dose limit, one of these workers received a whole-body dose of 670 mSv and two workers received beta skin doses estimated at 2 to 3 Sv. 408 workers received doses in excess of the annual limit of 50 mSv.

Release Assessments: Fukushima (2 of 2)

Tokyo Electric Power Company (TEPCO) has estimated that the incident at Fukushima Daiichi resulted in the release of the following quantities of radioactive material:

- Noble gases – 500 PBq
- Iodine-131 – 500 PBq
- Cesium-137 – 10 PBq
- Cesium-134 – 10 PBq

About 20% of the radioactive material came from Unit 1 and about 40% each from Units 2 and 3. Major releases began on about March 15, three days after evacuation of the population out to 20 km. Much of the release was initially pushed over the ocean to the east of the station, but a significant quantity passed over and deposited on the ground to the west.

After Release

In the next section of the lesson you will learn about dose rates, deposition, and plume mixtures. In general, we know that after a release:

- Dose rates will be variable
- Deposition will be complex
- Mixture may vary
- Models do not make reliably accurate predictions

Most dose projection computer programs projection use straight-line Gaussian dispersion models. Mathematically, you can calculate a concentration of radioactive material downwind and off- centerline, and, therefore, a dose. The reality of environmental factors such as river valleys, terrain features, building wake, and crosswinds, however, often doesn’t cooperate with mathematical formulas.

Whole-Body Dose and Plume Elevation

The projected whole-body dose at a location in the path of a release will vary depending upon whether the release is ground level or highly elevated. Elevation of the release can prevent high doses, as it did at Chernobyl, but cannot be predicted.

The side of the containment building is a likely failure point, leading to a ground level release. Even vented activity escaping through safety relief valves near buildings may be pulled down by building wake, effectively becoming a ground level release.

Plume Mixture (1 of 2)

The core damage state and timing of the release affects the mix of a release, causing the mixture in the plume to potentially change during the release.

Early in a release, normal coolant activity may be the only material released. As the accident progresses, gap activity (composed of other radioactive materials) may escape. Still later, as fuel melts, the composition of the release may change again.

Change in isotopic mixture in plume during release:

- Is different by core damage state.
- Can only make crude estimates.
- Can be confirmed by monitoring.
- Can change during release with wind direction.

Plume Mixture (2 of 2)

Often, a ratio of one radioisotope to a longer-lived radioisotope being released is used to differentiate release compositions. In the example shown in this image, strontium-89 is compared to cesium-137. During the gap release part of the incident depicted, no Sr-89 was released when the wind was blowing toward the northeast. However, when the wind shifted toward the northwest and the core melt release began, Sr-89 was evident. Later, when the wind shifted toward the southwest and vessel melt-through occurred, the ratio of Sr-89 to Cs-137 in the release increased significantly.

Deposition and Wind Shift

The actual dose for a major release can be elevated in any direction. For example, during the 1957 nuclear accident at Windscale, the following isotopes were released into the environment:

- 20,000 Ci of I-131
- 600 Ci of Cs-137
- 80 Ci of Sr-89
- 9 Ci of Sr-90

At TMI, the wind changed direction 360 degrees over 18 hours. Since a major release will most likely take place over several hours, wind shifts and high doses should be expected in several directions around the plant, not in a single direction. There is essentially no such thing as "downwind." The environment must be characterized (locate the deposited radioactive material).

Deposition Rate Variation with Surface, Location, and Time

Deposition rates following an accident will vary by surface, location, and time.

A significant part of the total dose to a population will be from deposited material.

Plume Direction (1 of 2)

Reasons why monitors at the plant may not record where the plume is going include:

- Diurnal heating and cooling at shorelines (lake effects)
- Local topographic obstacles
- Complex wind patterns

The list of reasons why monitors at the plant may not include where the plume is going continues on the next screen.

Plume Direction (2 of 2)

Additional reasons monitors at the plant may not record where the plume is going include:

- The wind moves in both horizontal and vertical planes and changes over the time of the release.
- If the monitor is placed in the line of the plume but the wind is moving upward, the monitor may not record the radiation from the plume at ground level. A single monitored measurement is insufficient to determine where a plume is going.
- The impact of release height will affect plume direction.

Experience and research have shown that the area affected by a reactor accident may be very large and complex (several states and/or countries). The public will demand proof of where contamination is and is not.

Lesson Summary

Let's summarize what you learned in this lesson:

- The greatest risk after an accident is to the population nearest the plant.
- It's difficult to predict which direction is actually downwind; monitor in all directions.
- Aerial and many ground-based monitoring teams will be needed.

In the next lesson you will learn about protective actions for reactor accidents and the emergency classification system.