SEVERE ACCIDENT MANAGEMENT: RADIATION DOSE CONTROL, FUKUSHIMA DAIICHI AND TMI-2 NUCLEAR PLANT ACCIDENTS

Roger SHAW
Shaw Partners LLC
United States

This presentation presents valuable dose information related to the Fukushima Daiichi and Three Mile Island Unit 2 (TMI-2) Nuclear Plant accidents. Dose information is provided for what is well known for TMI-2, and what is available for Fukushima Daiichi. Particular emphasis is placed on the difference between the type of reactors involved, overarching plant damage issues, and radiation worker dose outcomes. For TMI-2, more in depth dose data is available for the accident and the subsequent recovery efforts. The comparisons demonstrate the need to understand the wide variation in potential dose management measures and outcomes for severe reactor accidents.

ONTARIO POWER GENERATION FUKUSHIMA EMERGENCY RESPONSE DRILL STRENGTHENS AND LESSONS LEARNED

David W. Miller
North American Technical Centre
United States

Japan's Fukushima Daiichi severe nuclear accident in March 2011 has resulted in a reassessment of nuclear emergency response and preparedness in Canada. On May 26, 27 & 28, 2014 Ontario Power Generation (OPG) conducted the first North American full scale nuclear emergency response exercise designed to include regional, provincial and federal bodies as well as the utility. This paper describes the radiological aspects of the OPG Exercise Unified Response (ExUR) with emphasis on deployment of new Fukushima equipment on the Darlington site, management of emergency workers deployed in the vicinity of Darlington to collect environmental samples and radiation measurements, performance of dose calculations, communication of dose projections and protective actions to local, provincial and federal agencies and conduct of vehicle, truck and personnel monitoring and decontamination facilities.

The ExUR involved more than 1000 personnel from local, provincial and federal bodies. Also, 200 OPG employees participated in the off-site emergency response duties. The objective of the ExUR was to test and enhance the preparedness of the utility (OPG), government and non-government agencies and communities to respond to a nuclear emergency. The types of radiological instrumentation and mobile facilities employed are highlighted in the presentation. The establishment of temporary emergency rooms with 8 beds and treatment facilities to manage potentially contaminated injuries from the nuclear emergency is also described.
Severe Accident Management: Radiation Dose Control

Fukushima Daiichi and TMI-2 Nuclear Plants

ISOE Expert Group on Occupational Radiation Protection in Severe Accident Management

Nuclear Energy Institute
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Roger P. Shaw, CHP, RSO
Principal, Shaw Partners LLC
RELATIVE BACKGROUND

• Former Director of Radiation Protection (RP), Three Mile Island Nuclear Plant (post-accident)

• First RP Director of both TMI-1 and TMI-2
  • Radiation Field Operations, Radiological Engineering, Radiation Health, Radiation Instrumentation, Radiation Dosimetry

• Director of Occupational Safety & Health
RELATIVE BACKGROUND

- Directed the TMI-2 Radiological Controls Program from 1990 to the final shipment of damaged fuel to the DOE Idaho National Laboratory, and achievement of Post-Defueling Monitored Storage in 1993.

- First radiation worker to enter the TMI-2 damaged containment (entry #66) and perform radiological surveys of the Reactor Coolant Pumps and pressurizer (1983) – 15-20 rem/hr (150-200 mSv/hr).
RELATIVE BACKGROUND

- Director of the Radiological Controls & Occupational Safety Program at the Oyster Creek Nuclear Plant (1993-1997)

- BWR-2 commercial operation 1969
  ~ ‘sister’ plant to Fukushima Daiichi Units 1-4
Three Mile Island Unit 2

- Pressurized Water Reactor (PWR)
- NSSS: Babcock & Wilcox (B&W) – 880 MWe
- Engineer: Burns & Roe and Gilbert
- Constructor: United Engineers and Constructors
- Initial Criticality: 28 March 1978
- Commercial Operation: 30 October 1978
- Accident: 28 March 1979
- Effective Full Power Days (EFPD) – <100!
Three Mile Island Units 1 and 2
TMI-2 Control Room

No Replica Training Simulator Onsite - Unlike Today
TMI-2 Accident Chronology

- 28 March 1979 – 33 years ago
- 16 March 1979 “China Syndrome” movie released and in theaters around TMI
- 23 July 1980 – 1st Reactor Building Entry
- July 1984 – Reactor Vessel Head removed
- October 1985 – Defueling began
- July 1986 – 1st off-site shipment of reactor core debris
- January 1990 – Defueling completed
- 28 December 1993 - PDMS Approved by NRC
- Spent Fuel in Dry Storage at Idaho National Lab
Major Considerations for TMI-2 & Fukushima Daiichi Accidents

- Obvious – PWR vs. BWR
- Single Unit vs. Multiple Units
- Primary Containment Remained Intact
- Reactor Vessel Not breached
- Effluent Releases via Auxiliary Bldg. (except Kr-85)
- Spent Fuel Pool - not damaged and played no role
- No real site damage (except core damage)
- Hydrogen ‘burn’ but no hydrogen explosion
- No Station Blackout or offsite power loss
- No extensive detectable offsite contamination
- No required evacuation of general public
No Damage to Turbine Building (TMI-1 shown here)
Exemplary Leadership

- Strong Safety Culture — Before NRC Required
- Strong Senior Leadership
- President/Vice-President worked directly for Admiral Rickover — Father of U.S. Nuclear Navy
- Several Nuclear Navy Admirals served as Directors
- For extended time — >20 NRC Inspectors onsite
- State of Pennsylvania oversight
- Improved public outreach following poor start
  - Local Physicians trained after some abortions inappropriately recommended
  - Whole Body Counts offered to general public
Exceptional Radiological Controls

- Strong work management
- Exceptionally qualified staff hired
- High priority from Senior Management
  - Radiation Protection Policy
  - Radiation Protection Plan
  - Radiation Procedures – verbatim compliance
  - ALARA Committee
  - Mockups
  - Advanced Radiation Worker Training
  - Stop Work Authority at Radiation Technician Level
  - Pre- and post-job briefings
- Committed to Excellence
Innovation with Radiological Controls

- Digital Reading Dosimeters (DRD)
- Breathing Zone Air (lapel) Samplers
- Powered Air Purifying Respirators (PAPR)
- Whole Body Contamination Monitors
- Ice vests and Vortex suits for worker cooling
- Hydration for high heat area entries
- Completely assisted PPE donning and removal for all Reactor Build. entries – fully ready rescue crews
- Multiple dosimeter packs where needed (up to ~10 dosimeters due to radiation stratification)
- Command & Control Room for RB entries
TMI-2 PDMS Requirements

- <1% Failed Fuel remaining
- No real potential for liquid or airborne effluents
  - Reactor Building – “Breather” system with passive ventilation system – maintained at atmospheric pressure
  - Liquids sampled for any groundwater intrusion/effluent
- No fire damage potential
- All accident generated water (AGW) processed
- Long-term radiological surveillance program in place
- Decommissioning funds in escrow
- Unit-2 to be decommissioned when Unit-1 done
- Others
Recovery and Defueling Issues

- Major engineering undertaking
- Extensive radiological controls challenge
- Performing tasks not performed before
- RV Core Bore Drilling
- Plasma Arc Torch cutting of fuel and reactor internals
- Use of long-handled tools – hydraulics and hand
- Special design equipment
- Highly specialized contractors needed
- Major use of robotics…
Robotics Photos from Video

T.M.I. Rover

Designed for Use at Three Mile Island Nuclear Power Plant, Pittsburgh, Pennsylvania – Standard’s six wheel, 570 lb. undercarriage was developed for use in contaminated areas for initial surveillance as part of the radioactive waste cleanup program for the power plant. The undercarriage measures 50” long x 29” wide x 19” high and operates electrically by remote control.
TMI “Workhorse” Hydrolasing Robotics

50k psi Water
Standard Fukushima Robotics
More Advanced Fukushima Robotics
D&D Categories (U.S.)

DECON (Decontamination)

SAFSTOR (Safe Storage) – TMI-2 PDMS – Essentially meets SAFSTOR requirements

ENTOMB
Q: Should *Key* Robotics be part of Regional or Country Emergency Equipment Centers?

- Strategic Alliance for FLEX Emergency Response (SAFER) in the U.S. model or others?
- Many lessons learned from 9/11 FDNY - compatibility
- Radiation and Video Monitoring as a minimum?
- Utilize local Bomb Squad robotics and quickly adapt? Non-nuclear experience issues?
- Utilize most local known NPP robotics via MOU?
Dose Estimates for Cleanup

TOTAL CUMULATIVE RADIATION WORKER DOSE

*MINIMUM* – 2000 person-rem (20,000 person - mSv)*

*MAXIMUM* – 8000 person-rem (80,000 person - mSv)*

*OTHER ESTIMATES* – AS HIGH AS >20,000 person-rem (>200,000 person - mSv)

*NUREG-0683 – Estimated (1981)*
# Major PDMS Activities

## TMI-2 Worker Dose for Major Activities

1986 - 1989

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>PERSON-REM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defueling Operations (reactor vessel only)</td>
<td>698</td>
</tr>
<tr>
<td>Defueling Support (tool repairs, water cleanup)</td>
<td>1058</td>
</tr>
<tr>
<td>Reactor Building Miscellaneous (robotics, crane ops, radwaste, etc.)</td>
<td>765</td>
</tr>
<tr>
<td>Decontamination (outside the reactor building)</td>
<td>424</td>
</tr>
<tr>
<td>Routine Operations (ops, chemistry, rad con outside reactor building)</td>
<td>277</td>
</tr>
<tr>
<td>Ex-Vessel Defueling (pressurizer, OTSG, etc.)</td>
<td>216</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>3438</strong></td>
</tr>
</tbody>
</table>
Worker Cumulative Dose

*Estimated TOTAL*

1979-1993 to reach PDMS

~6,600 person-rem (66,000 mSv)

- ~62,500 person-mSv*
- ~3,500 person-mSv**

*GPU Nuclear TMI-2 Annual Dose Report
**USNRC NUREG-0713
NOTE: Total includes some TLD and some Self-Reading Dosimeter data
Worker Cumulative Dose through 1989

**TABLE 5**

LIFETIME OCCUPATIONAL RADIATION EXPOSURE FOR TMI-2 WORKERS*

<table>
<thead>
<tr>
<th>LIFETIME DOSE RANGE (millirem)</th>
<th>PERCENTAGE OF TMI-2 WORKERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 1000</td>
<td>35</td>
</tr>
<tr>
<td>1000-3000</td>
<td>11</td>
</tr>
<tr>
<td>3000-5000</td>
<td>12</td>
</tr>
<tr>
<td>5000-10,000</td>
<td>21</td>
</tr>
<tr>
<td>10,000-20,000</td>
<td>17</td>
</tr>
<tr>
<td>Greater than 20,000</td>
<td>4</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100</td>
</tr>
</tbody>
</table>

* Lifetime exposures include occupational doses received at TMI-2 and all other facilities where persons have worked.
TMI-2 Worker Overexposures

- Twelve (12) instances during initial accident response
- WB doses from TMI-1 post accident RCS sample
  4.1 rem (41 mSv) by 2 workers
  3.9 (39 mSv) rem by 1 worker
- One (1) additional in 1986 – handled a fuel chunk
- NO acute injuries
- Each individual received a medical evaluation
- Internal doses generally low – NO overexposures
- NO overexposures due to Discrete Radioactive Particles (DRPs or “hot particles”)
- Total number of individuals with overexposures = 13
Q: RCS Samples to Determine Failed Fuel – Are they worth taking?

- Caused 3 WB doses in excess of regulatory limits
- Lost chemistry & radiological count room
- No way to count RCS sample onsite – dose rates
- Shipped offsite on C-130 Air Force Plane
- No proper shipping papers – NRC ‘sanctioned’
- Better alternative method? What precision needed?
PPE Issues Played a Major Role
Care needed with Sr-90/Y-90 and alpha !!
Reactor Building Entrance Airlock
Remote Defueling Operation Over Reactor Vessel
Remote Shielded Rotating Work Platform
Personnel Protective Equipment for Platform Work
Training to visually identify Fuel/Corium
Reactor Vessel Turbidity Problems
Reactor Vessel Turbidity Problems
By January 1990, defuelers completed removing approximately 99 percent of the core debris from the reactor vessel — thereby eliminating any possibility of a chain reaction occurring in the plant. The work was slow; at times workers removed debris piece-by-piece. However, removing the damaged fuel was necessary to protect the safety of the workers and the public.

Monitored storage will mark the successful completion of the Cleanup Program goal by removing any radiological hazard to the public, TMI workers and the environment. During monitored storage, the reactor building is to be locked, but accessible for monitoring by a full-time staff.

Above: Landmark photograph shows empty bottom of the Unit 2 reactor vessel. The vessel bottom is at the bottom right of the photograph, which was taken from videotape.

Top Right: International attention was once again focused on TMI-2 when samples were removed from the reactor vessel. The samples were sent around the world for analysis to determine what effect the accident had on the vessel. Here a straight-edged tool is used to determine that the surface of the sample is flat.

Bottom Right: The empty reactor vessel.

Defueled Reactor Vessel Cutaway

Reactor Vessel Fuel Removed 1990
Spent Fuel Pool Bay for both Units

TMI-1: bottom of photo with normal configuration

TMI-2: top of photo with Submerged Demin System (SDS)
USDOT Approved Rail Shipping - Spent Fuel
## Fukushima Worker Doses

Cumulative dose of all the workers worked at Fukushima Daiichi site
(Accident March 11-December 2013)

<table>
<thead>
<tr>
<th>Dose (mSv)</th>
<th>The number of TEPCO employees</th>
<th>The number of Subcontractor employees</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;250</td>
<td>6</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>200-250</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>150-200</td>
<td>24</td>
<td>2</td>
<td>26</td>
</tr>
<tr>
<td>100-150</td>
<td>118</td>
<td>20</td>
<td>138</td>
</tr>
<tr>
<td>75-100</td>
<td>255</td>
<td>112</td>
<td>367</td>
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<tr>
<td>50-75</td>
<td>323</td>
<td>850</td>
<td>1173</td>
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<tr>
<td>20-50</td>
<td>607</td>
<td>4197</td>
<td>4804</td>
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<tr>
<td>10-20</td>
<td>544</td>
<td>3875</td>
<td>4419</td>
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<tr>
<td>5-10</td>
<td>431</td>
<td>3687</td>
<td>4118</td>
</tr>
<tr>
<td>1-5</td>
<td>707</td>
<td>6835</td>
<td>7542</td>
</tr>
<tr>
<td>1&gt;</td>
<td>1070</td>
<td>7717</td>
<td>8787</td>
</tr>
<tr>
<td>Total</td>
<td>4086</td>
<td>27297</td>
<td>31383</td>
</tr>
<tr>
<td>Max(mSv)</td>
<td>678.8</td>
<td>238.42</td>
<td>678.8</td>
</tr>
<tr>
<td>Average(mSv)</td>
<td>23.6</td>
<td>10.97</td>
<td>12.61</td>
</tr>
</tbody>
</table>

**SOURCE:** Health, Labour and Welfare Ministry of Japan
# Fukushima Worker Doses

Cumulative dose of all the workers worked at Fukushima Daiichi site (2013.4-2013.12)

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<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>75-100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>50-75</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20-50</td>
<td>19</td>
<td>377</td>
<td>396</td>
</tr>
<tr>
<td>10-20</td>
<td>54</td>
<td>1370</td>
<td>1424</td>
</tr>
<tr>
<td>5-10</td>
<td>157</td>
<td>1592</td>
<td>1749</td>
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<tr>
<td>1-5</td>
<td>643</td>
<td>3284</td>
<td>3927</td>
</tr>
<tr>
<td>1&gt;</td>
<td>735</td>
<td>4104</td>
<td>4839</td>
</tr>
<tr>
<td>Total</td>
<td>1608</td>
<td>10727</td>
<td>12335</td>
</tr>
<tr>
<td>Max(mSv)</td>
<td>34.7</td>
<td>39.7</td>
<td>39.7</td>
</tr>
<tr>
<td>Average(mSv)</td>
<td>2.61</td>
<td>4.69</td>
<td>4.42</td>
</tr>
</tbody>
</table>

**SOURCE:** Health, Labour and Welfare Ministry of Japan
Some Key Points Given to 5 Japan Parliament Members in June 16 Meeting

- Simple conclusion could be that Daiichi was 3-4 times worse than TMI-2
- Not the case – may present ~8-12 times the magnitude of a challenge
- TMI-2 had no extensive plant damage
- No penetration through reactor vessel
- The task is enormous and will require incredible effort and cooperation
- National and International level of effort with the best minds and talent necessary
Some Key Points Given to 5 Japan Parliament Members in June 16 Meeting

- Major Hot Spots exist (throughout plants)
- Fuel Fragments (highly radioactive) - >10,000 mSv/hr
- Discrete Radioactive Particles - fuel, fission and activation products
- These DRP’s are invisible to the eye - can act like ‘fleas’ due to electrostatic charge
- Plutonium (strong public reaction expected)
- Tritium – radioactive ‘water’ – cannot remove like particles (problematic effluent)
Some Key Points Given to 5 Japan Parliament Members in June 16 Meeting

- Build airplane type hanger structure to contain each Daiichi units
- May need to adjust regulations for radiation worker Dose Limits such as 100 mSv in 5 years
- To clean to 95%, may require 50-100k trained radiation workers
- Radioactive waster processing and volume reduction is critical
- NO nuclear plant in the world has seen a 15 meter tsunami and 9.0 earthquake
Temporary and Permanent Protective Covers for Unit 1
Kyle Drubek On the outskirts of Fukushima city, a farmer spreads zeolite -- intended to absorb and concentrate radioactive cesium -- across his rice field in preparation for planting.
Dedicated to the memory of
Mr. Wataru Mizumachi