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Benchmarking Studies with RASCAL and Other Fast-Running Emergency Response Codes

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Why Participate in Current Benchmarking Studies with RASCAL?

- Determine how RASCAL performs under study conditions to identify potential improvements and obtain feedback from external organizations
  - Code-to-code comparisons
  - Code-to-environmental-data comparisons
- Gain knowledge of attributes and performance other emergency response codes
  - Interest in RASCAL performance among user community
- Routine activity for code maintenance and development in the Office of Nuclear Regulatory Research
- Fukushima accident prompted current benchmarking studies of emergency response code capabilities and performance

Fukushima Daiichi Units 4 and 3 After the Accident

(Source: “"Reflections on Fukushima," USNRC NUREG/KM-008, December 2014)

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RASCAL Use During NRC Response To Fukushima

- Goals of NRC response:
  - Understand the accident, predict plant response, suggest corrective actions
  - Assess Japanese protective actions
  - Make recommendations for protection of U.S. citizens in Japan
  - RASCAL and other codes supported U.S. team response

- Encountered difficulties obtaining data on plant conditions and local weather
  - Pertinent to ongoing benchmarking studies

- Lesson learned: modify RASCAL to run multiple source terms and extend release duration for calculations


Collapsed tower

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Purpose of Electric Power Research Institute Study

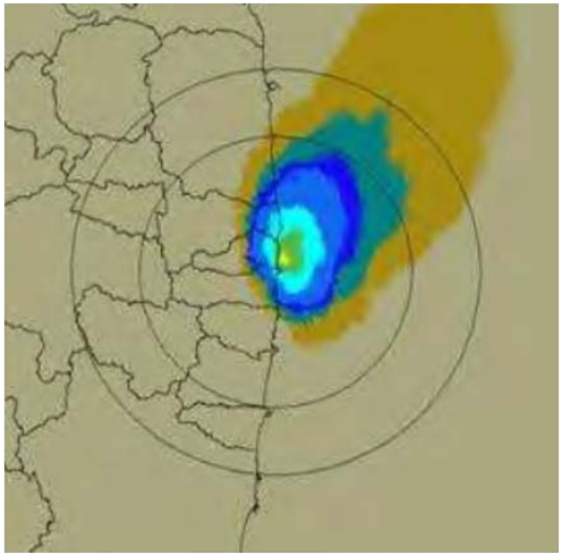
- Understand performance of emergency response codes typically used in U.S.

- From a real event, compare radionuclide releases predicted by codes against actual field measurements by assessing code capabilities to:

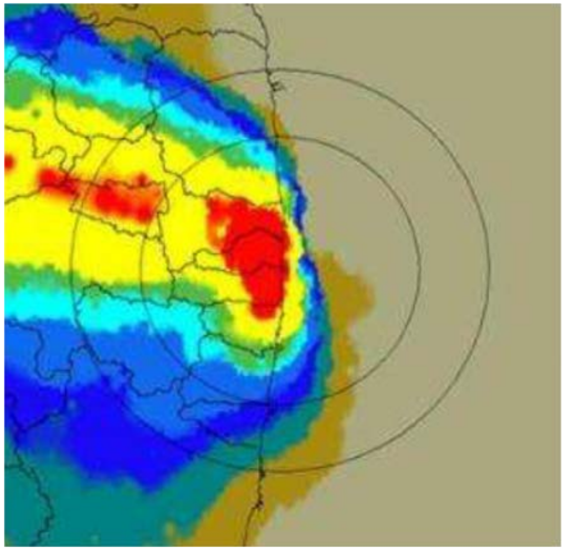
  1. Estimate source terms of a multi-unit, beyond design-basis accident
     - Fukushima accident progression (3 reactor units)
     - Participants used same accident progression data to perform calculations
     - Code-to-code comparison (RASCAL/MAAP source term predictions)

  2. Evaluate direction/extent of plume propagation
     - RASCAL predictions of airborne and ground radionuclide concentrations compared to Fukushima environmental data
     - Code-to-environmental data comparison (RASCAL output/EPRI data)

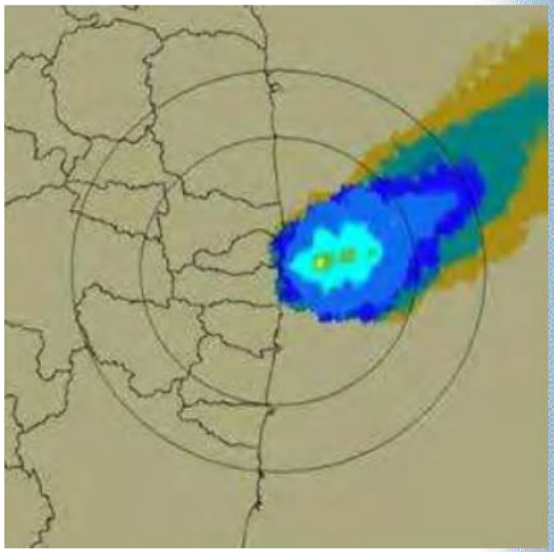
Unit 2 Releases Mainly Contributed To Land Contamination



Unit 1



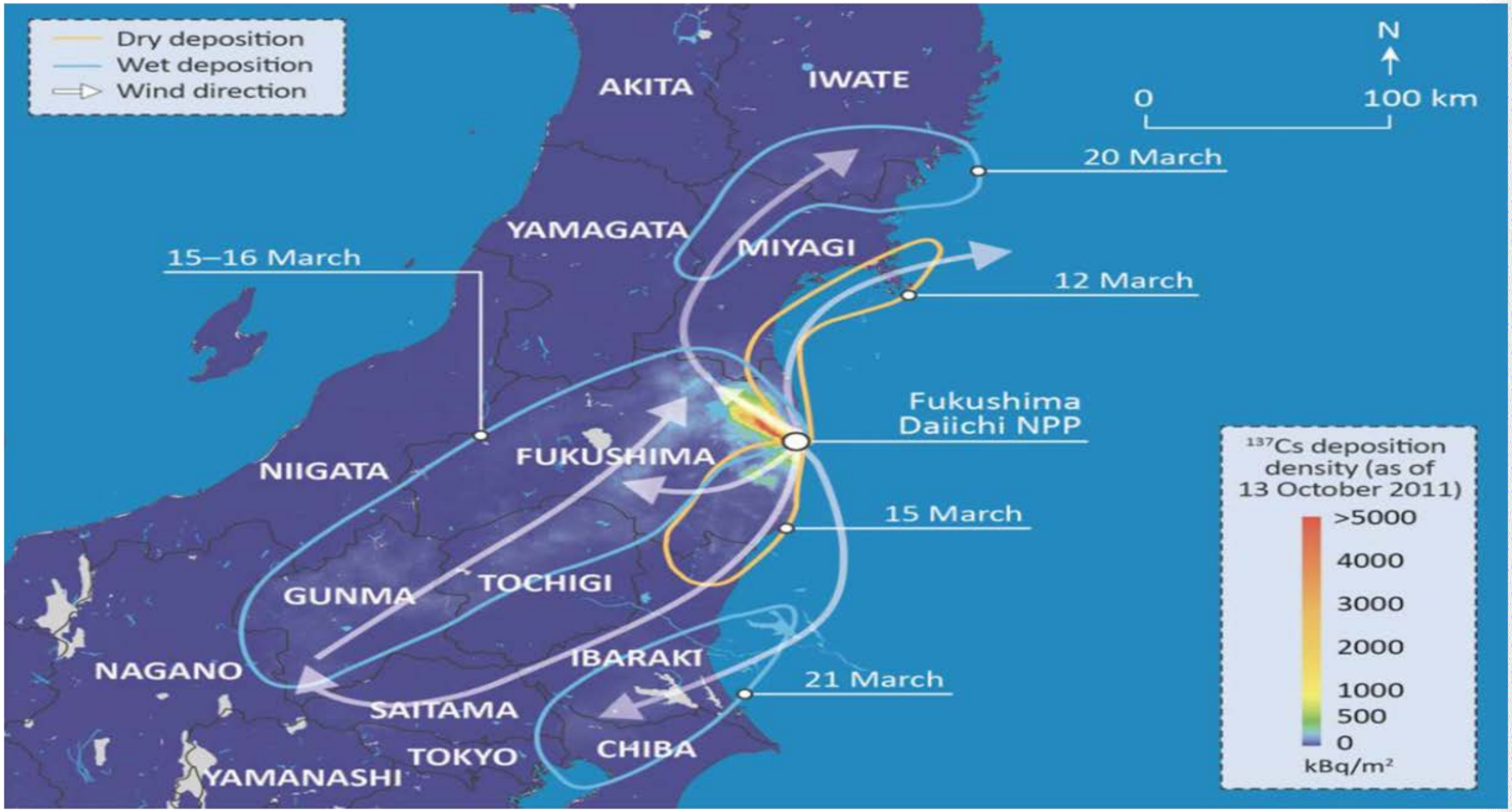
Unit 2



Unit 3

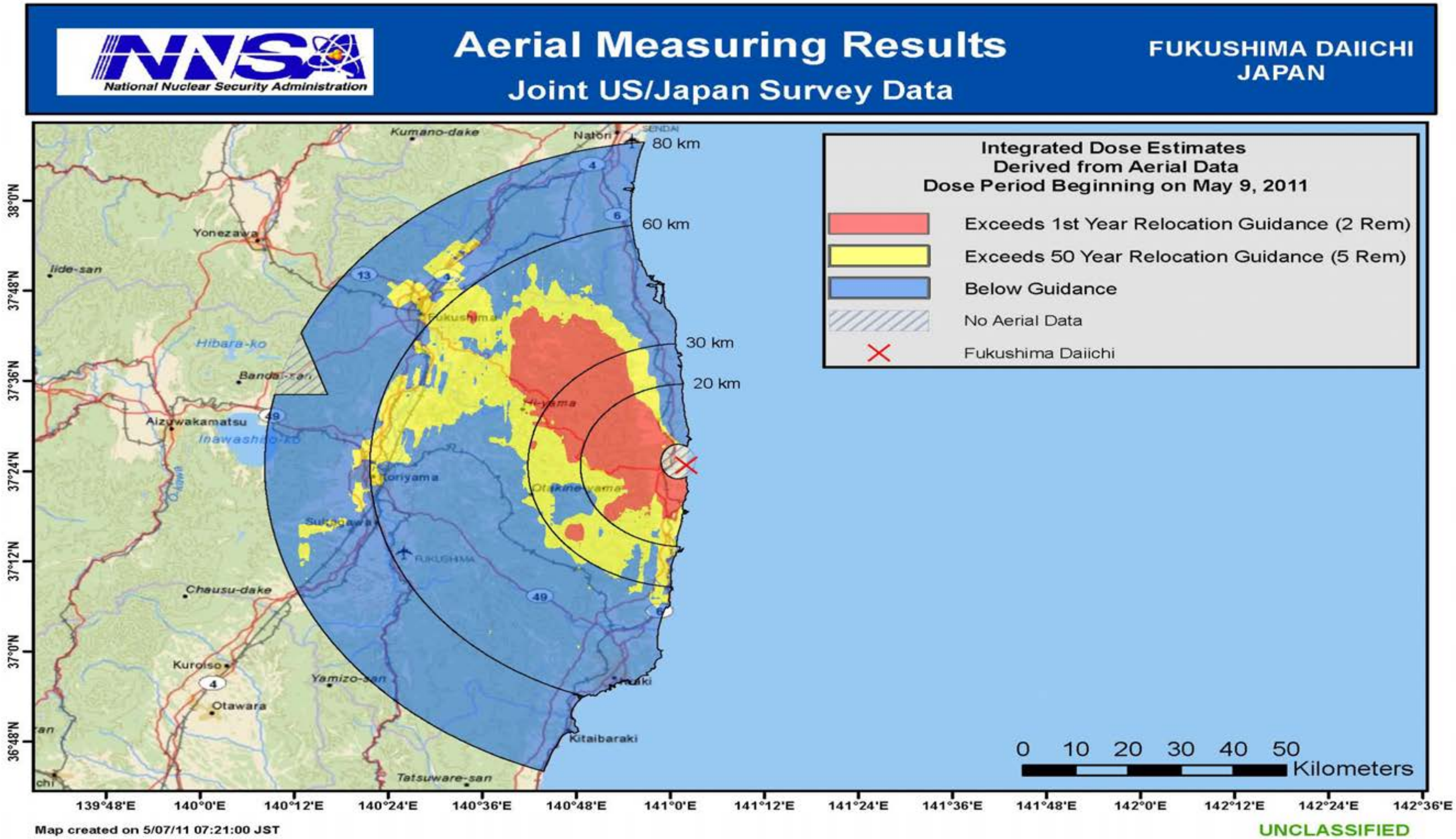
(Source: JNES and JAEA, December 16, 2012)

Timing and Locations Of Main Deposition Events



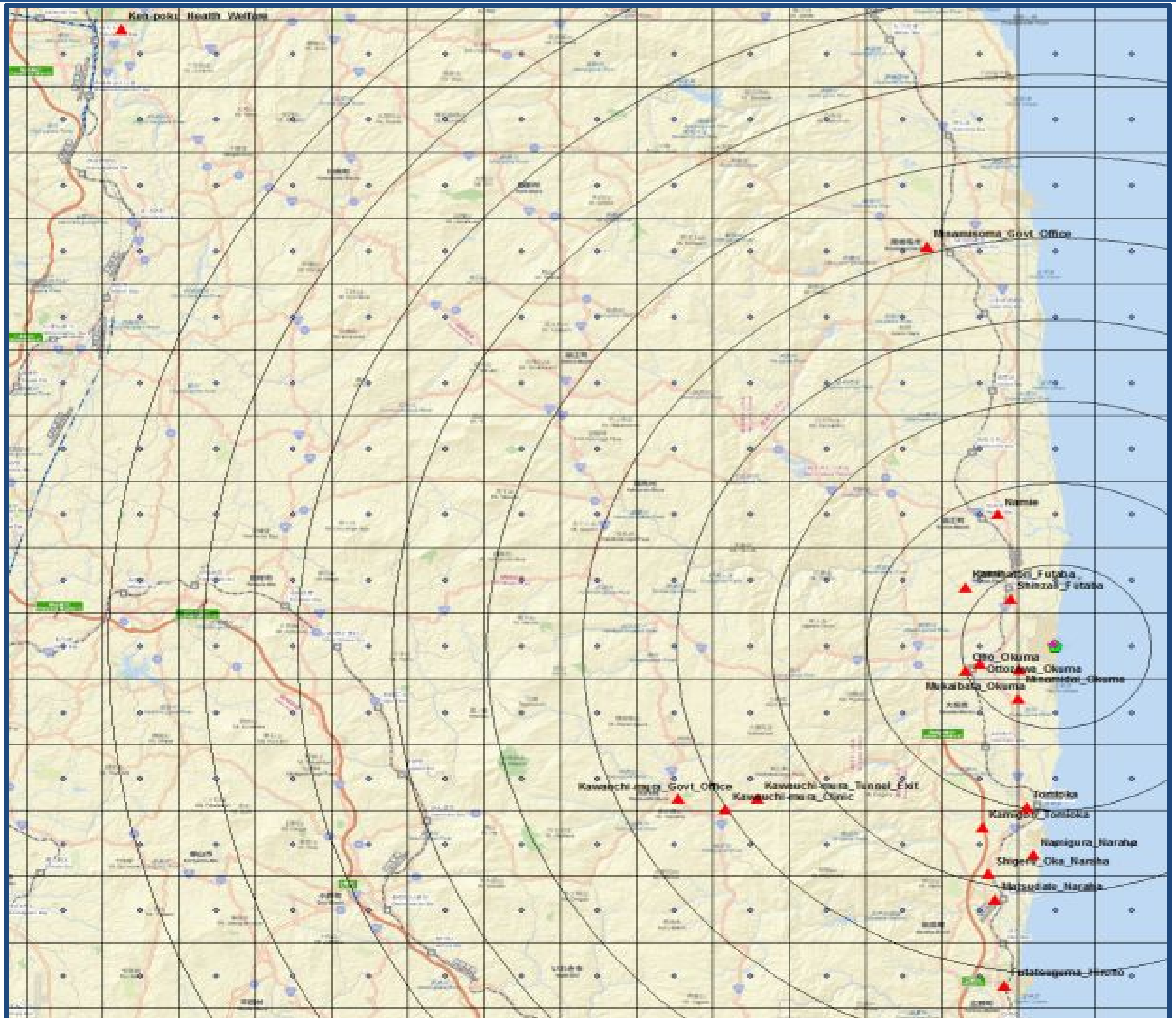
(Source: IAEA, August 31, 2015)

Ground Deposition: May 9, 2011



Virtual Meteorological Measurement Locations For RASCAL Calculations

Environmental Measurement Locations For RASCAL Calculations



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Selection of Code Input Parameters from EPRI Data

- Comprehensive EPRI accident progression dataset required careful selection of RASCAL input parameters for each Fukushima unit
- RASCAL and MAAP5 source term predictions are being studied to identify similarities and differences in models, explain results
- Technical considerations:
  - Sparse local meteorological data
  - Large number of radiological measurements
  - Continued development of accident progression knowledge and publication of environmental data. Actual extent of core damages and source terms currently under investigation.
- Report publication: expected in 2016

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Purpose of Organization for Economic Cooperation and Development / Nuclear Energy Agency Study

- Study of "fast running" emergency response codes used internationally
  - RASCAL chosen as U.S. code

- Determine why Fukushima dose predictions differed, with the following objectives:

  1. Summarize the state-of-the art of fast-running emergency response codes

  2. Recommend areas for code improvement by summarizing strengths, weaknesses and gaps

  3. Improve confidence, understand differences in results through cross-comparisons of code performance

NEA "FASTRUN" Benchmarking Study Code Selection

Codes selected based on ability to perform the following:

- Calculate source terms, estimate core damage and physical barrier condition
- Project radiological doses from radionuclide releases during early phase
- Run with few input parameters
- Capable of handling additional input parameters during accident to improve dose projections
- Model a variety of reactor technologies
- Execute rapidly in support of protective action decision-making
- Accurately predict source terms and radiological doses

NEA "FASTRUN" Benchmarking Study Participant List

Reactor types and accident sequences analyzed	
Canadian CANDU	Station blackout
French PWR (external filters)	LOCA
Swedish BWR (external filters)	Loss of heat removal
US BWR and PWR	Long-term station blackout

> 20 codes studied by 20 organizations (12 countries and 2 international organizations)			
Belgium	CURIE V5	IAEA	InterRAS
Canada	RASCAL v4.3, VETA	Italy	IDRA
Denmark	ARGOS	Korea	XSOR, SURSOR, MACCS2
European Commission	MAAP4	Poland	MELCOR, RODOS
France	MER, PERSAN, C3X	Slovakia	ESTE
Germany	ABR , ASTRID, QPRO MCTransport, RODOS	Sweden	RASTEP
India	ACTREL	US	RASCAL v4.3.1

NEA "FASTRUN" Benchmarking Study Sites

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NEA "FASTRUN" Benchmarking Study RASCAL Calculations

Source Term

- Tested new long-term station blackout accident sequence in RASCAL v4.3
- Radionuclide releases to atmosphere based on SOARCA analyses
  - Good agreement between SOARCA and RASCAL source terms

Meteorology

- NEA met data included snow and rain to test code handling of precipitation
- Calm winds handled by RASCAL low-wind speed correction factors

Dose Calculations

- Comparison to U.S. Environmental Protection Agency's *Protective Action Guide Manual* (10 -50 mSv TEDE; 50 – 250 mSv thyroid)
- Plume passage is major contributor to dose projection
- No shielding, KI, or evacuation to reduce dose projections

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NEA "FASTRUN" Benchmarking Study Example Data Set for Code Input

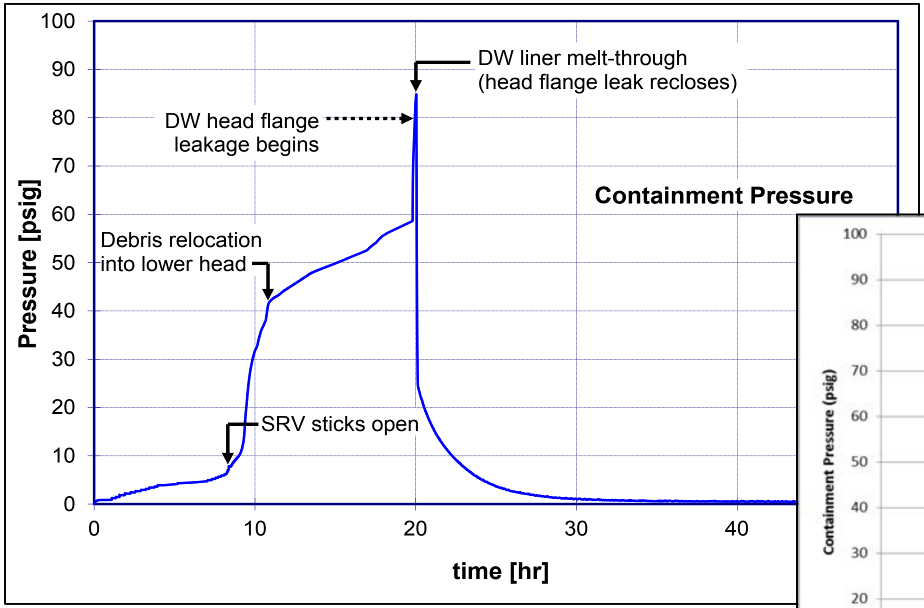
Parameter	Time Information is Available	Parameter Value
Reactor name	1 hour after accident	Peach Bottom
Reactor design	1 hour after accident	General Electric BWR with Mark I containment
Thermal power	1 hour after accident	3514 MWth
Brief description of the accident	1 hour after accident	LTSBO caused by earthquake; loss of all AC power; one safety relief valve opened at 1 hour; Operators control RCIC after 2 hours
Reactor shutdown (Yes/No)	1 hour after accident	Yes
If yes, time of reactor shut down	1 hour after accident	< 15 minutes
Power Available (Yes/No)	6 hours after accident	No AC or DC power available at 6 hrs (AC power lost at 0:00 and batteries depleted at 4:00)
Core uncovered/Loss of heat sinks (Yes/No)	6 hours after accident	No. Core still covered at 6 hrs
If yes, time the core is uncovered/heat sinks lost	6 hours after accident	Water level reaches top of active fuel at 8.4 hrs
Core temperature	6 hours after accident	550° K (fuel cladding temperature at core mid-plane)
Containment pressure	1 day after accident	690,000 Pa @ 20 hrs; drywell liner melt-through;138,000 Pa @ 24 hrs
Containment failed (Yes/No)	1 day after accident	Yes
If yes, time of containment failure	1 day after accident	20 hrs
If no, venting status (e.g. has venting started, flow rate)	1 day after accident	No venting

NEA "FASTRUN" Benchmarking Study Default RASCAL Inputs For BWR LTSBO

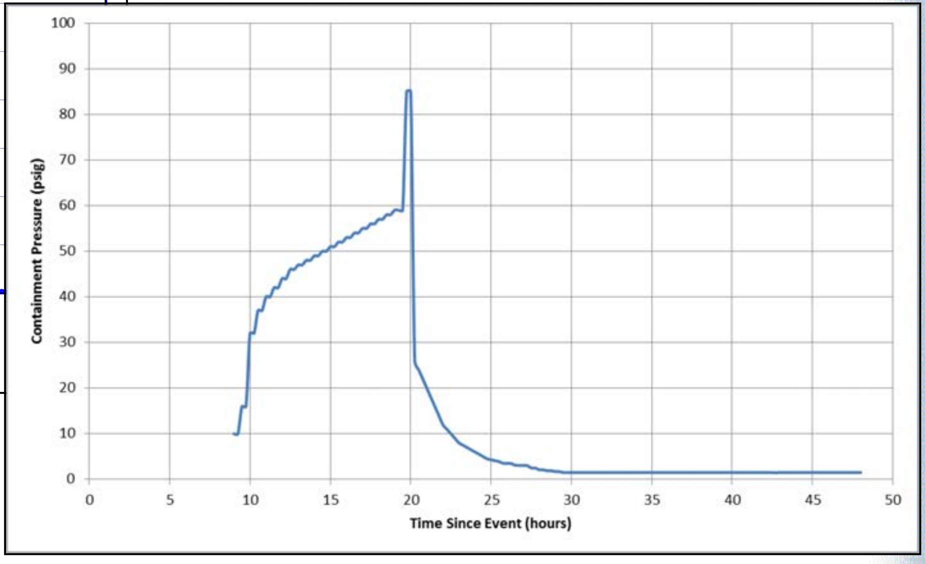
- Used RASCAL default plant parameters to obtain *initial* dose projections
  - No ac power: 4 hours of core cooling via batteries (duration adjustable)
  - Standby Gas Treatment System and sprays unavailable
  - Releases through a saturated suppression pool
- After loss of core cooling, 6 more hours until fission product release begins
  - Default RASCAL assumption for LTSBO at BWRs
- First fission product releases to atmosphere at 10 hours after shutdown
- Design containment leak rate of 0.5% per day
  - Containment failure, timing based on available data
- Atmospheric release terminated at 48 hour
- FASTRUN meteorological data used for calculations

NEA "FASTRUN" Benchmarking Study Revised RASCAL Inputs For BWR LTSBO

Containment leak rates for RASCAL runs based on SOARCA containment pressure data and use of the containment hole size feature in RASCAL v4.3

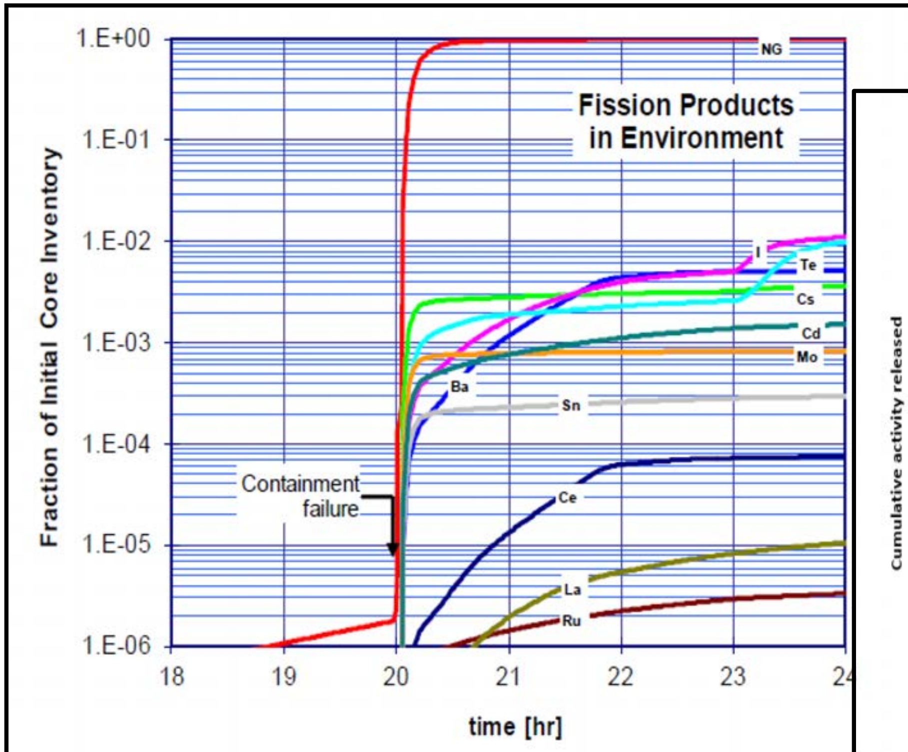


SOARCA Containment Pressure Data

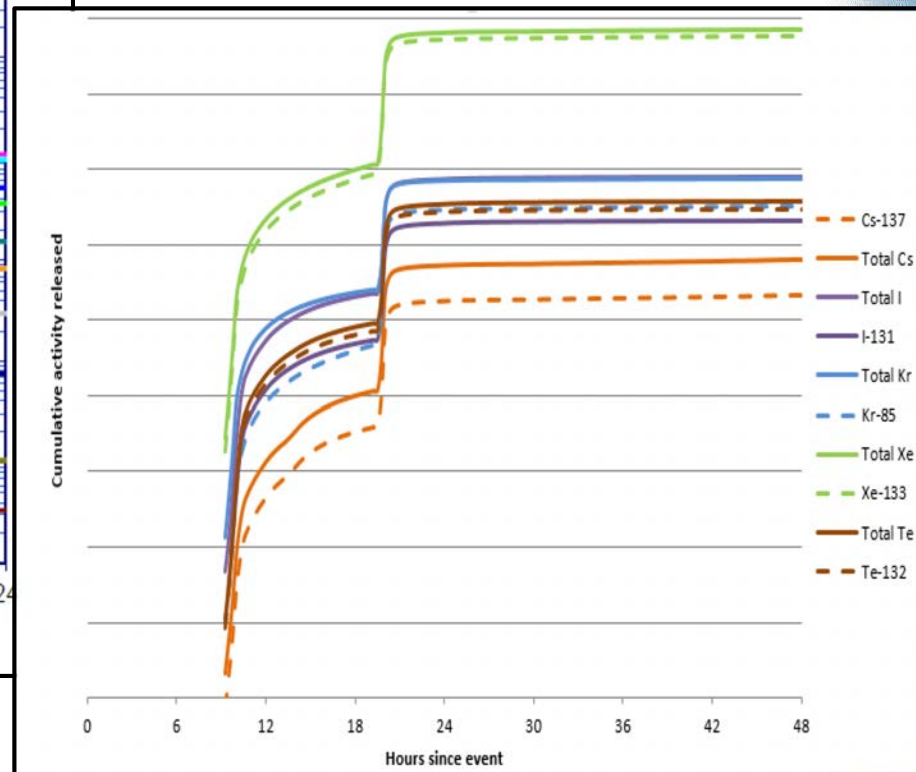


RASCAL Containment Pressure (input to code)

NEA "FASTRUN" Benchmarking Study Example Results For BWR LTSBO



SOARCA Radionuclide Release Estimate



RASCAL Radionuclide Release Estimate

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NRC Staff Observations

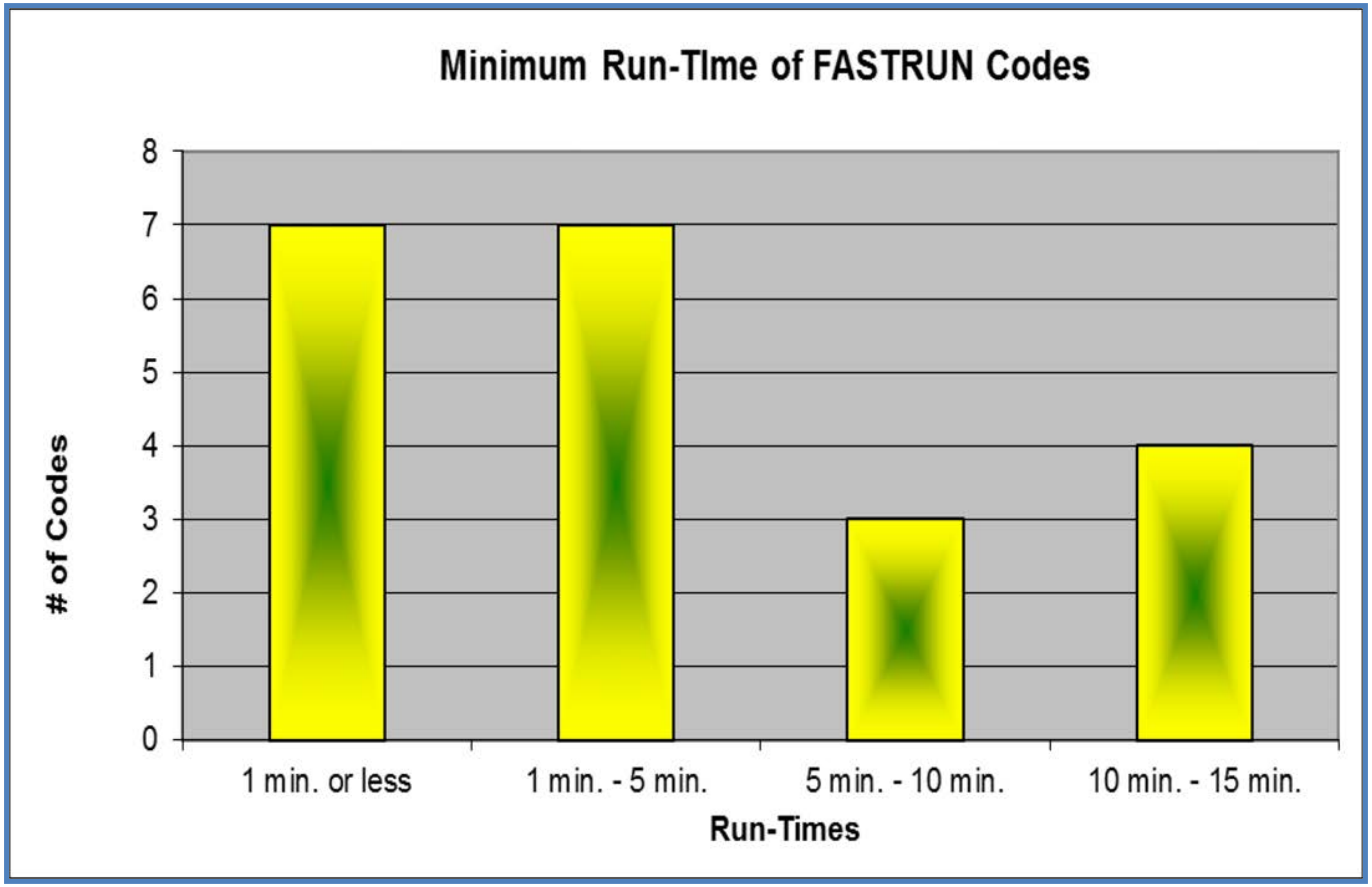
- Most codes can be set up in <20 minutes and run in <10 minutes
  - 11 codes calculate source term; 6 calculate dose; 6 calculate both
  - Not all codes model H explosions, aqueous pathway, multi-unit releases

- Radionuclides assessed vary among codes
  - Most codes consider Cs, I, Te and Xe

- Differences in calculated source terms, doses expected with limited data

- Major factors contributing to differences in code performance include:
  - Radionuclide release models (core to containment to atmosphere)
  - Capability of modeling plant systems
  - Dispersion model handling wide range of weather conditions, local terrain
  - *User assumptions are key: proper selection of parameter values*

NEA "FASTRUN" Benchmarking Study



NEA "FASTRUN" Benchmarking Study
NRC Staff Observations

- Results driven by code operator assumptions
  - *Selection of representative input parameters is key*
- Future studies of fast-running emergency response codes
  - Additional analysis of dispersion models
  - More emphasis on dose calculation methodology, ATD model differences
  - Less emphasis on source term comparisons
- Develop a forum for exchanging best practices and hands-on training
- Consider one code (or limited set) for assessing international incidents?
- FASTRUN report publication: expected in 2016

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Benefits of EPRI and NEA Benchmarking Studies (So Far)

- Analyses used to test RASCAL v4.3 and v4.3.1 functionality
  - Versions released in 2013 and 2014

- Check alignment with MELCOR models and SOARCA data, MAAP models, other mechanistic codes that are not typically used in emergency response

- Lessons learned (so far)
  - Enhance RASCAL user interface to adjust source terms more easily
  - Incorporate more power plant designs and sites outside the US
  - Increase training, user forums for international emergency response community benefit

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Thank You For Your Attention!

Questions?

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Backup Slide: Fukushima Radionuclide Release Estimates

Release Mode	Noble Gas (PBq)	I-131 (PBq)	Cs-134 (PBq)	Cs-137 (PBq)
Containment Venting	5	1	0.02	0.01
Reactor Building Explosion	10	3	0.07	0.05
Uncontrolled Release from Reactor Building	500	500	10	10
* 1 PBq = $1.0 \times 10^{+15}$ Bq = 27,000 Ci				

(Source: TEPCO, March 10, 2015)