Canada's Nuclear Regulator

2011 WNU SUMMER INSTITUTE
AUGUST 10 - CHRIST CHURH, OXFORD, UK

FUKUSHIMA DAIICHI NPP EVENT AND ASSOCIATED RADIOACTIVE SOURCE TERM – CNSC'S INITIAL RESPONSE

Prepared by: CNSC Staff
Presented by: Dr. Ali El-Jaby
Canadian Nuclear Safety Commission

OUTLINE

- PART I
  - About the CNSC
  - CNSC initial response
- PART II
  - Reactor and fuel description (“BWR 101”)
  - Simplified accident sequence
  - Source-term modelling & results
  - Current plant status
- PART III
  - Regulatory path forward

Canada's Nuclear Regulator

PART I – CNSC MANDATE AND INITIAL RESPONSE

Canadian Nuclear Safety Commission
Commission canadienne de sûreté nucléaire

Canada

CANADIAN NUCLEAR SAFETY COMMISSION – ***“CNSC”***

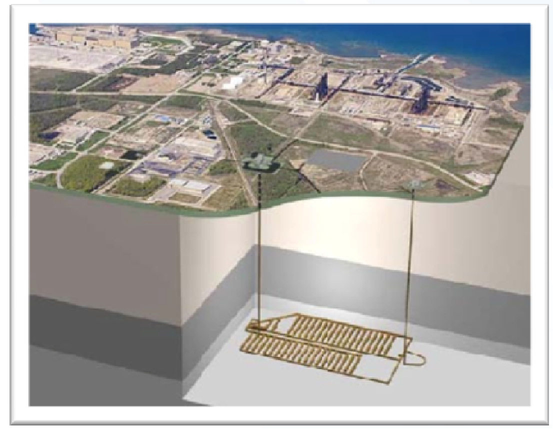
- Established May 2000, under the ***Nuclear Safety and Control Act***
- Replaced the ***Atomic Energy Control Board*** of the ***1946 Atomic Energy Control Act***
- ***Independent Nuclear Regulator for over 65 years***

CNSC MISSION

Protect the health, safety and security of persons and the environment; and implement Canada's international commitments on the peaceful use of nuclear energy

CNSC REGULATES ALL NUCLEAR ACTIVITIES AND FACILITIES IN CANADA

- Uranium mines and mills
- Uranium fuel fabricators and processing
- Nuclear power plants
- Waste management facilities
- Nuclear substance processing
- Industrial and medical applications
- Nuclear research and education
- Export/import control



…FROM CRADLE TO GRAVE

CNSC FUKUSHIMA RESPONSE

- ***Emergency Operations Centre (EOC)*** activated March 11 AM
- ***Nuclear Emergency Organisation (NEO)*** staffed in accordance with CNSC ***Emergency Response Plan (ERP)*** – adapted to foreign emergency
- 24/7 operation
  - Executive
  - Technical
  - Liaison
  - Communications
  - Logistics

CNSC EOC COMMAND

CNSC FUKUSHIMA RESPONSE

- CNSC role
  - Evaluate situation and possible outcomes
  - Provide credible information and advice
  - ***CONTINUE TO REGULATE***
- Actions
  - Support the Government of Canada
  - Worked closely with other departments (Health, Environment, Foreign Affairs, Public Safety)
  - Established working links with international counterparts (USNRC, UKONR, ASN-France)
  - Sent expert to IAEA (Dr. V. Khotylev)

CNSC REGULATORY RESPONSE

- Issued order on March 17 under 12(2) of the NSCA – to all nuclear facilities:
  - Review initial lessons learned
  - Re-examine safety cases
  - Implement immediate actions and report on long-term measures
- Issued order on March 22 under 12(2) of the NSCA to all other facilities

CONFIRMING CONTINUED SAFETY OF OUR FACILITIES

CNSC REGULATORY RESPONSE

- CNSC staff carried out focused NPP and facility inspections
  - Seismic qualification
  - Fire
  - Flooding
  - Backup power
  - Hydrogen igniters and passive recombiners
- On-going inspections against external hazards

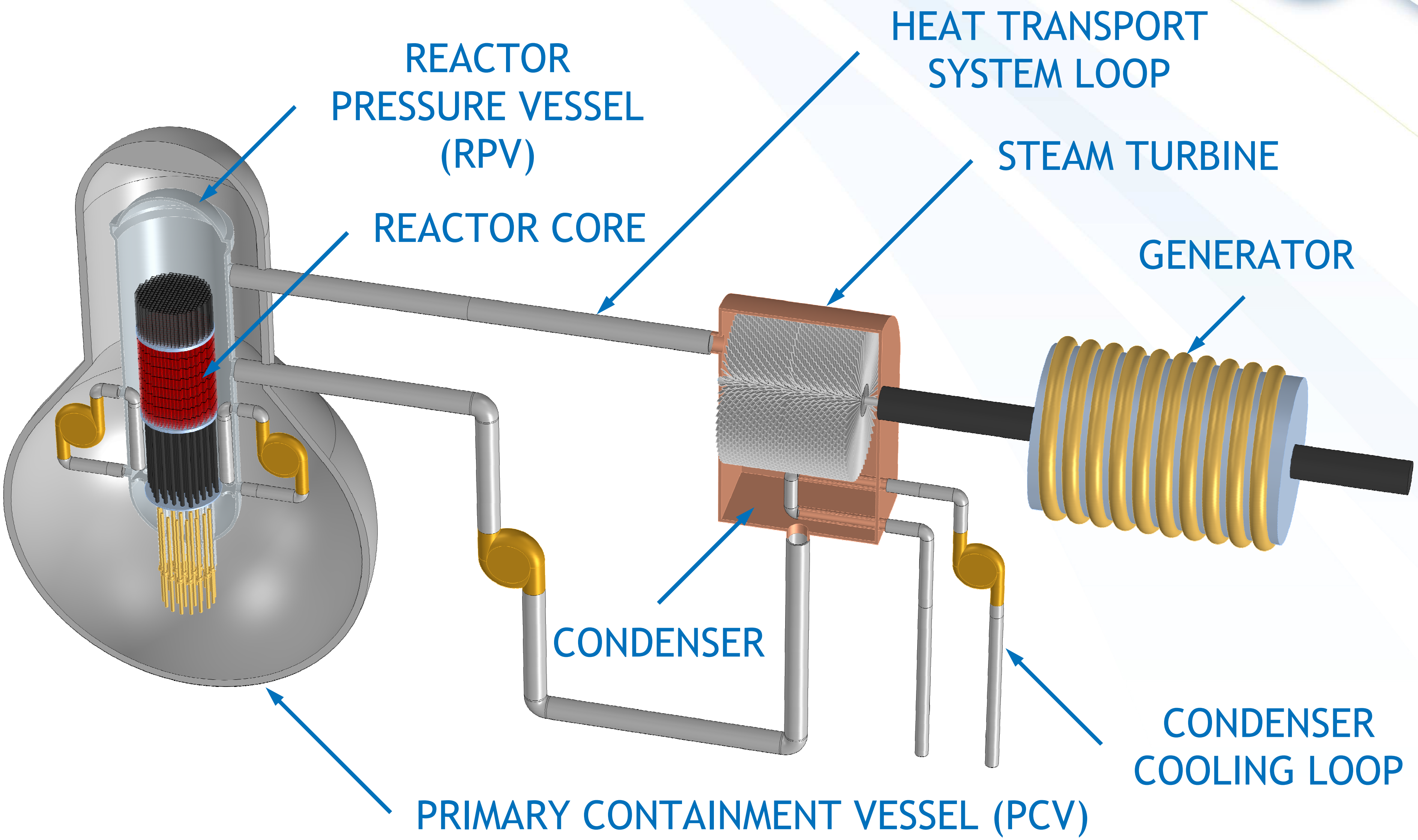
Canada's Nuclear Regulator

PART II – TECHNICAL ASPECTS OF CNSC RESPONSE TO THE FUKUSHIMA DAIICHI NPP EVENT

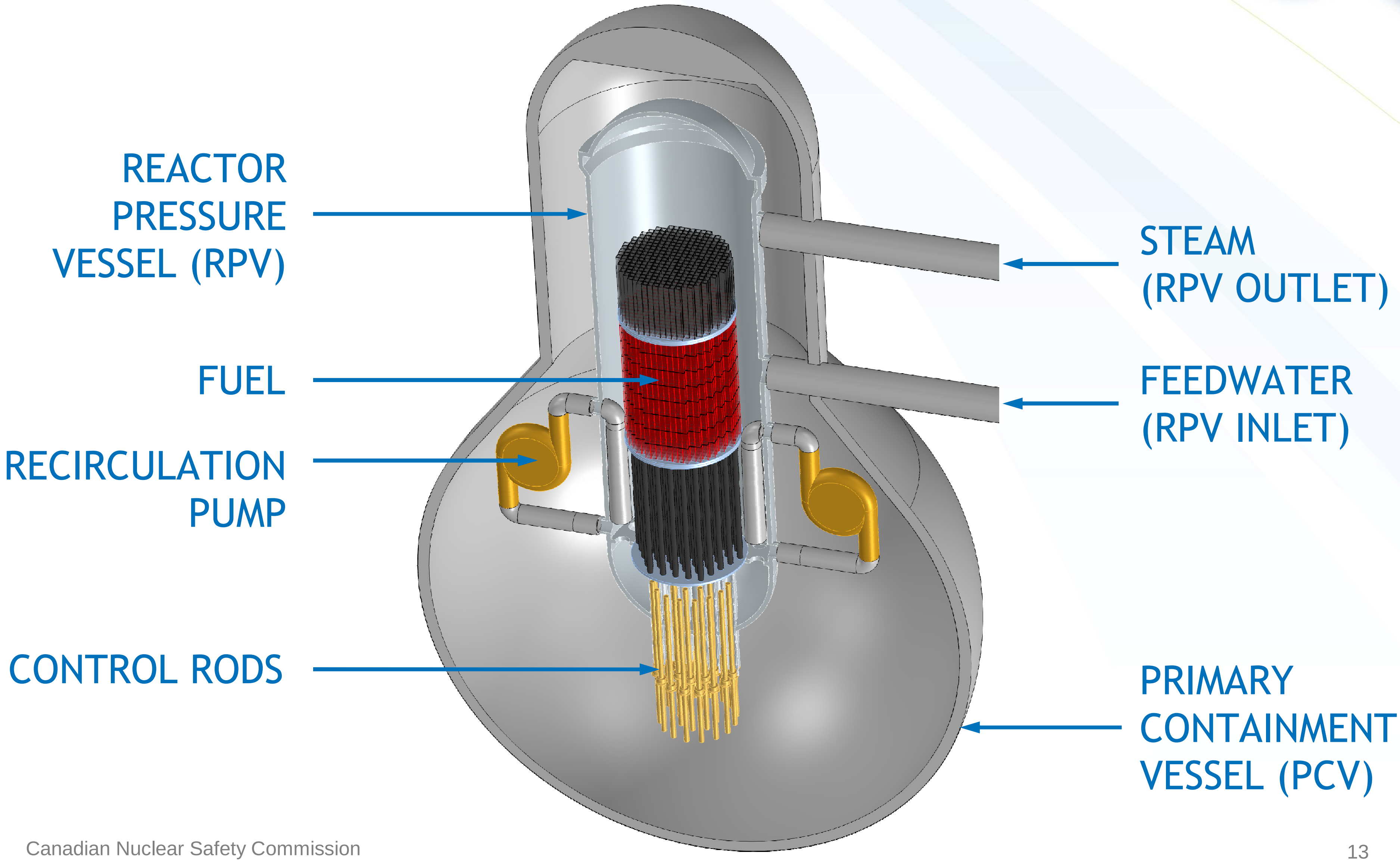
Canadian Nuclear Safety Commission Commission canadienne de sûreté nucléaire

Canada

BOILING WATER REACTOR

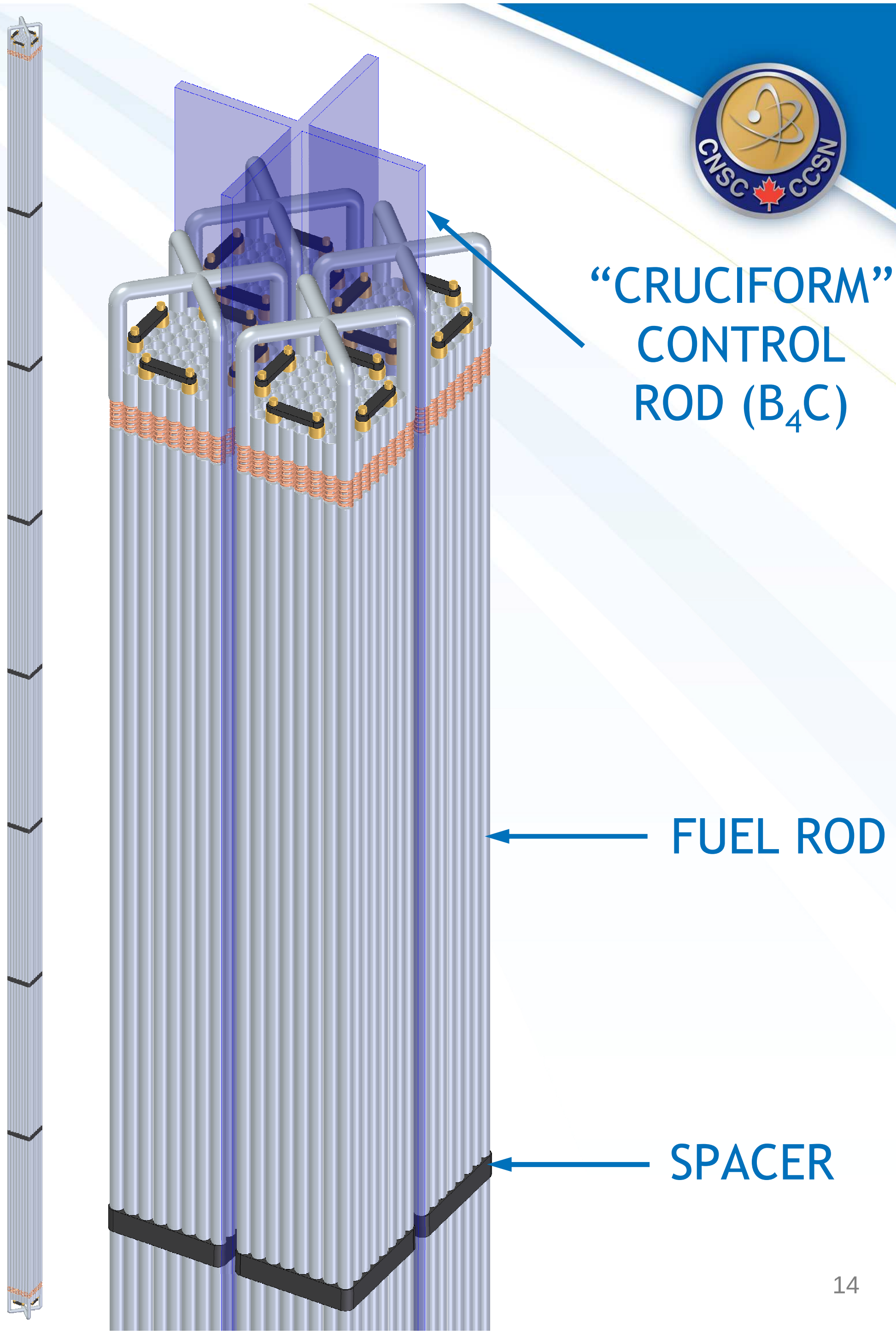


BOILING WATER REACTOR



BWR FUEL

- Fuel rods deployed in 8 × 8 assemblies
- 400-700 per core
- 13.9 cm × 13.9 cm
- 4.47 m total length (3.76 m active fuel)
- 320 kg total mass
- 208 kg UO_2 fuel
- 103 kg Zircaloy (cladding)



FUEL (AND CORE) SAFETY

- Ensure safety → core must be in “3C” state:
  - ***COOLED***
  - ***CONTROLLED***
  - ***CONTAINED***
- 3C is necessary for all modes of reactor operation
- Protect against fuel damage and potential releases of fission products to the environment

FUEL (AND CORE) BEHAVIOUR UNDER ACCIDENT CONDITIONS

- 1/2 core exposure
  - Cladding temperature rise but no significant core damage
- 2/3 core exposure
  - Cladding temperature ~900°C
  - Ballooning and cracking of cladding
  - Fission products released from fuel-to-clad gap
- 3/4 core exposure → core damage sequence accelerated

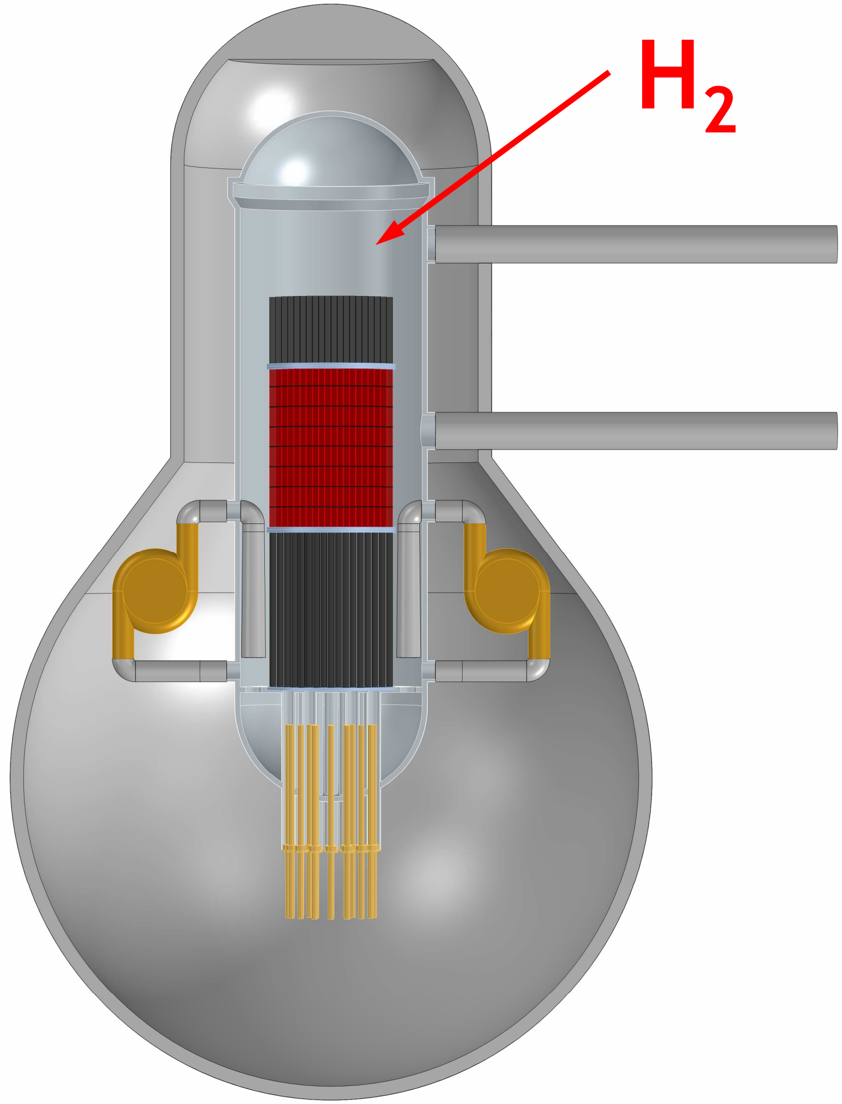
FUEL (AND CORE) BEHAVIOUR AFTER 3/4 CORE EXPOSURE

Cladding Temperature	Fuel Behaviour
> ~1200°C	Zirconium cladding reacts in steam atmosphere → highly exothermic reaction which further heats up core $(Zr + 2H_2O(g) \rightarrow ZrO_2 + 2H_2)$
> ~1800°C	Zirconium cladding begins to melt
> ~2400°C	Fuel assembly structure begins to “candle” into “non-coolable” geometry → i.e., core falls apart

SIMPLIFIED EVENT SEQUENCE

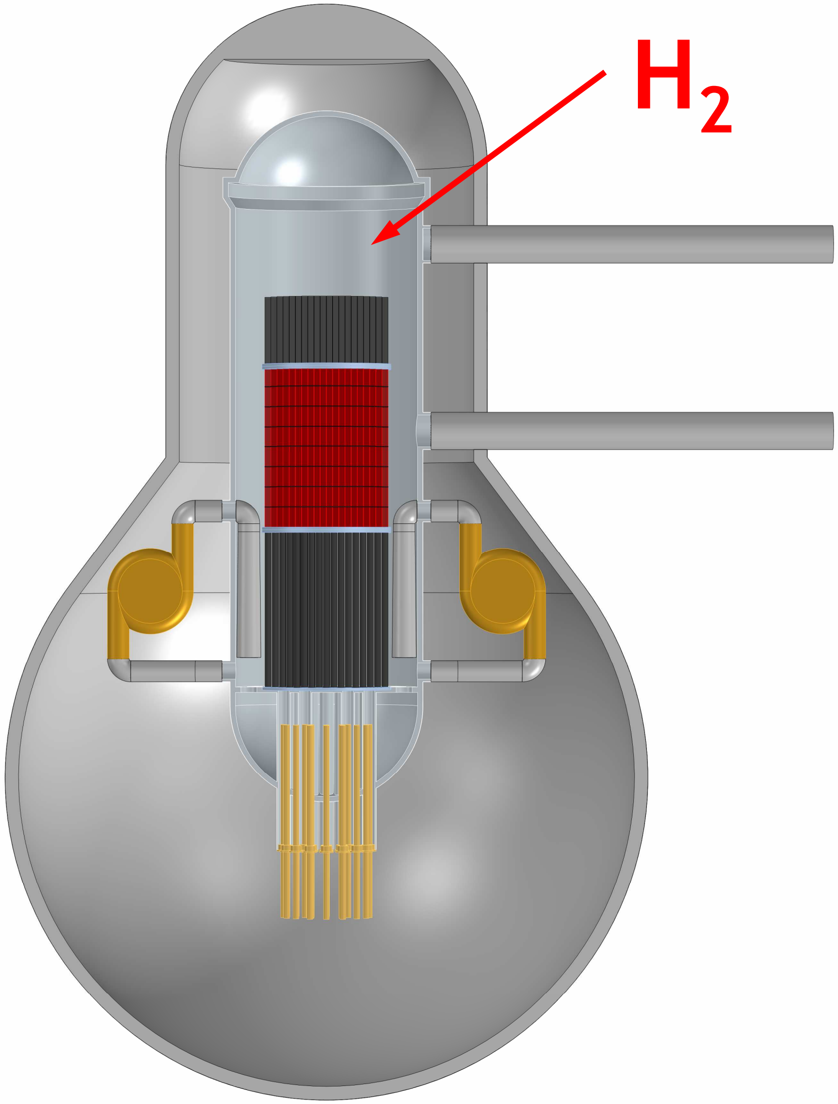
- During normal operation reactor provides power to cooling pumps (via steam turbine)
- Earthquake → auto shutdown (as designed and intended)
  - Core decay heat 7% of reactor power
  - Core cooling provided via back-up power (diesel generators) to pumps and heat exchangers to remove decay heat
  - Pools are also continually cooled to ensure integrity of spent fuel
- 14 m tsunami following earthquake damaged back-up power supply → ***NO COOLING TO REACTOR CORES OR SPENT FUEL POOLS***

SIMPLIFIED EVENT SEQUENCE



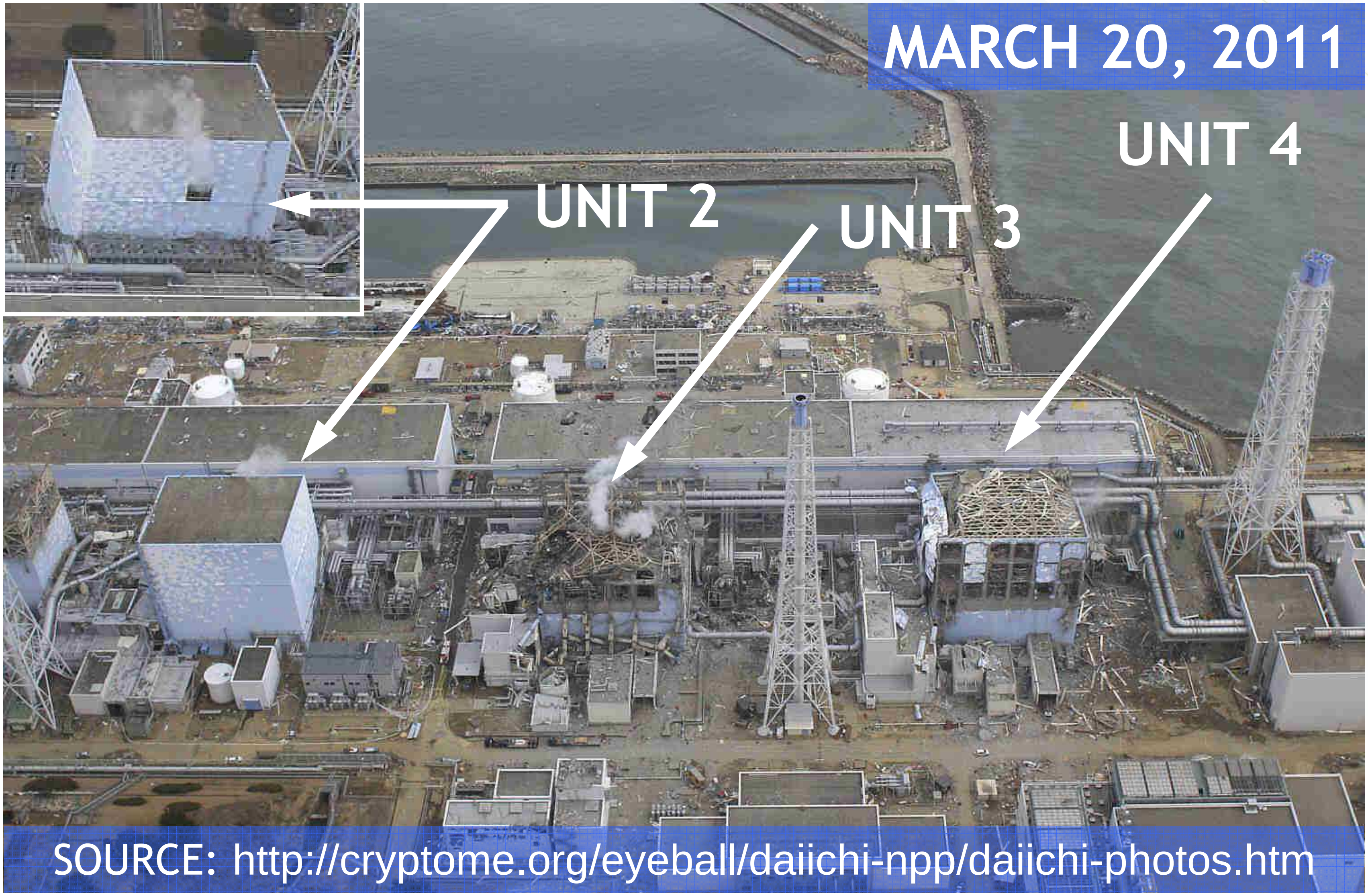
- No core cooling → fuel temperature increases
- $H_2O(\ell) \rightarrow H_2O(g)$
- Cladding reaction in $H_2O(g)$: $Zr + 2H_2O(g) \rightarrow ZrO_2 + 2H_2$
  - Exothermic: 5.8×10^6 J·kg^{-1}
  - Rapid temperature increase
  - Onset of cladding damage and fission product release
- Cladding reaction in air (O_2): $Zr + O_2 \rightarrow ZrO_2 + H_2$
  - Exothermic: 1.2×10^7 J·kg^{-1}
  - Significant cladding damage and further fission product release

SIMPLIFIED EVENT SEQUENCE



- Hydrogen build up in the reactor pressure vessel
- Eventually hydrogen finds its way into the reactor building (via bypass/dry well/wet well)
- Potential for hydrogen explosion when H_2 and O_2 > 5% of atmosphere

SIMPLIFIED EVENT SEQUENCE



SOURCE TERM DEVELOPMENT

- CNSC tasked to provide advice to Health Canada on the consequences to the population
- CNSC tasked to develop an estimate of the amount of radioactive material that might be released → ***SOURCE TERM***
- Source term combined with weather models to predict atmospheric dispersion of radioactive material → develop dose models to population
- Protective measures (shelter, KI pills, EZ) instituted based on predicted dose models

SOURCE TERM DEVELOPMENT

- Primary objectives were to ***PROTECT***:
  - Canadians in Japan (incl. Embassy Staff)
  - Canadians in Canada
  - The Canadian environment
- Advice based on projected releases from the entire Fukushima Daiichi NPP site
- Projected releases based on a postulated ***CREDIBLE WORSE CASE (CWC)*** scenario

SOURCE TERM DEVELOPMENT

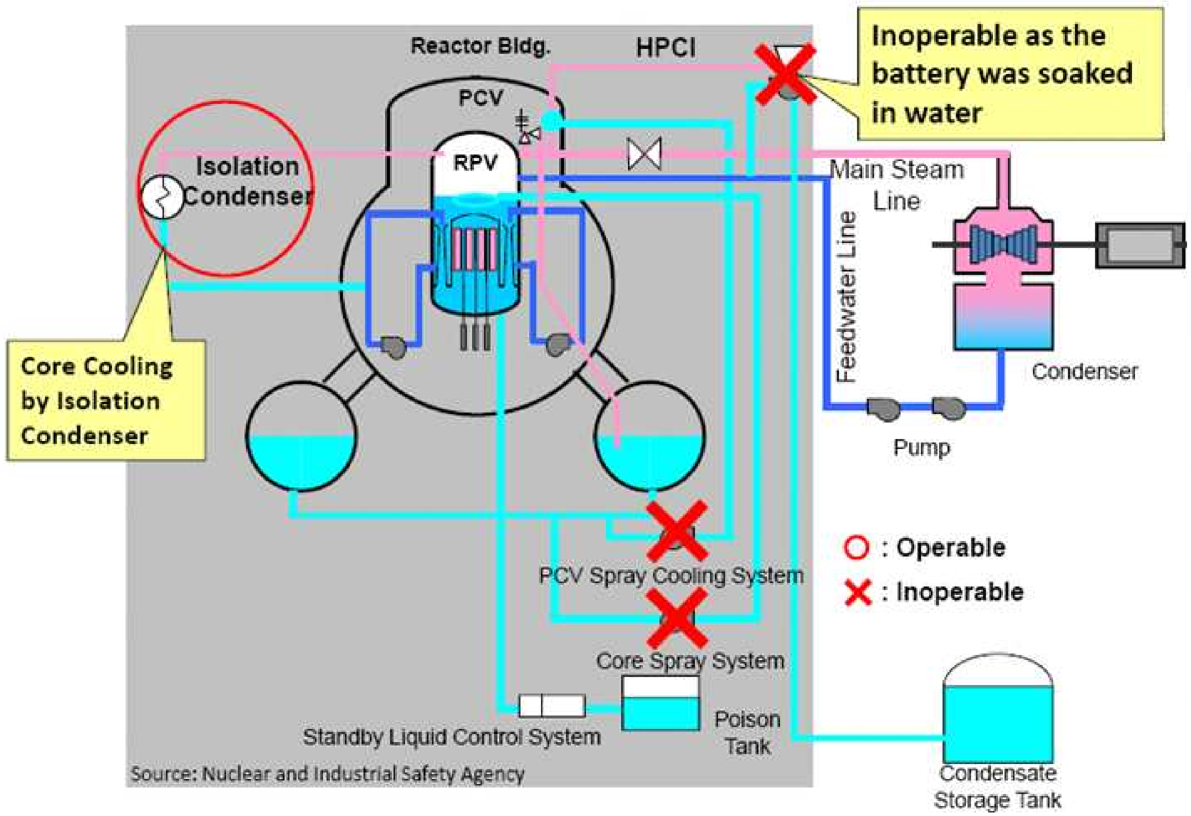
- Information and data from various points of contact
  - Government of Canada (HC-RPB, EC-CMC)
  - International counterparts and agencies (USNRC, UKONR, ASN-France)
  - Canadian Embassy in Tokyo
  - Canadian Mission in Vienna (IAEA)
  - Japanese Government (NISA, MEXT)
  - TEPCO

SOURCE TERM DEVELOPMENT: SOFTWARE

- RASCAL 4.1 – **R**adiological **A**ssessment **S**ystem for **C**onsequence **A**na**L**ysis
- ORIGEN-S (**O**ak **R**idge **I**sotope **GEN**eration)
  - Isotopic depletion and decay module in the SCALE (**S**tandardised **C**omputer **A**nalyses for **L**icensing **E**valuation) code system

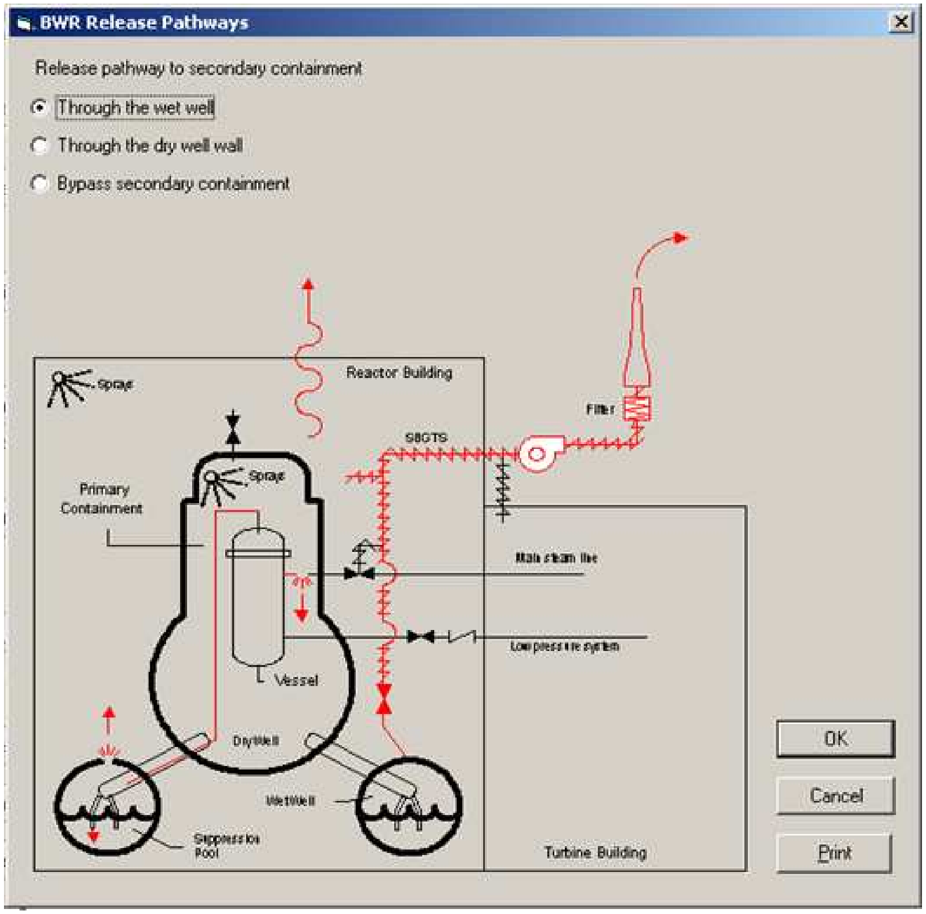
SOURCE TERM DEVELOPMENT: PLANT CONDITIONS

- Exact plant conditions were not known
- Ideally → the following information would have been available:

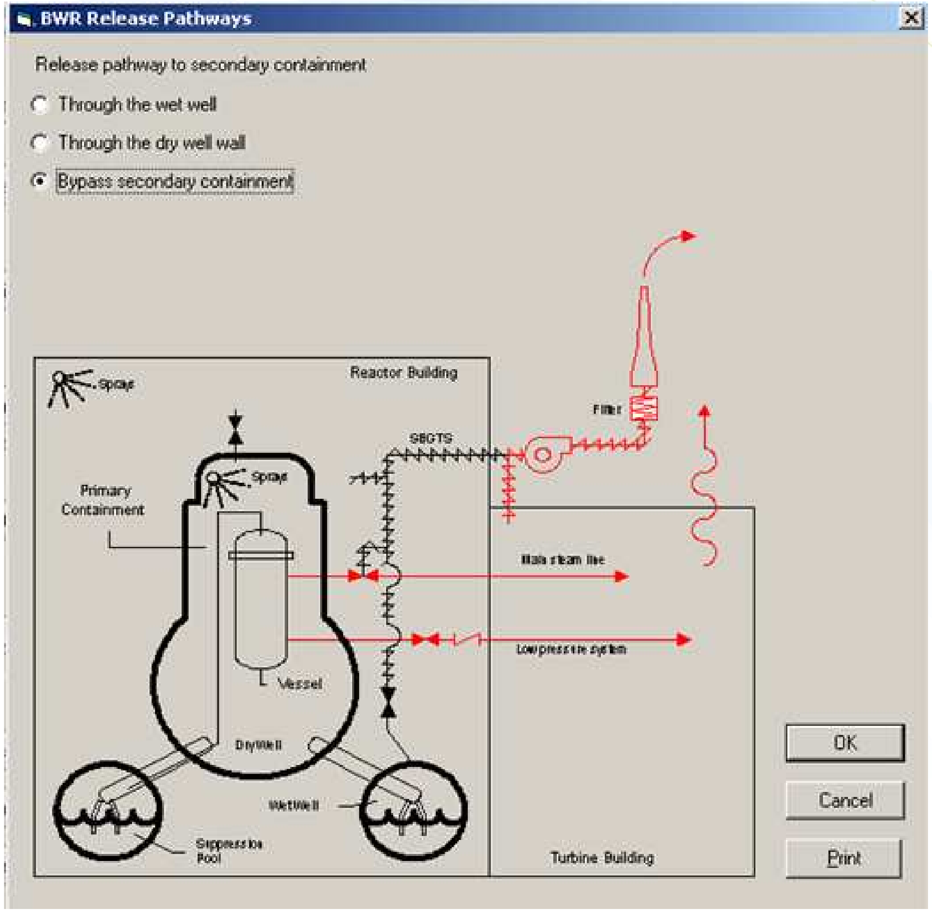


SOURCE TERM DEVELOPMENT: RELEASE PATHWAYS

Through the wet well

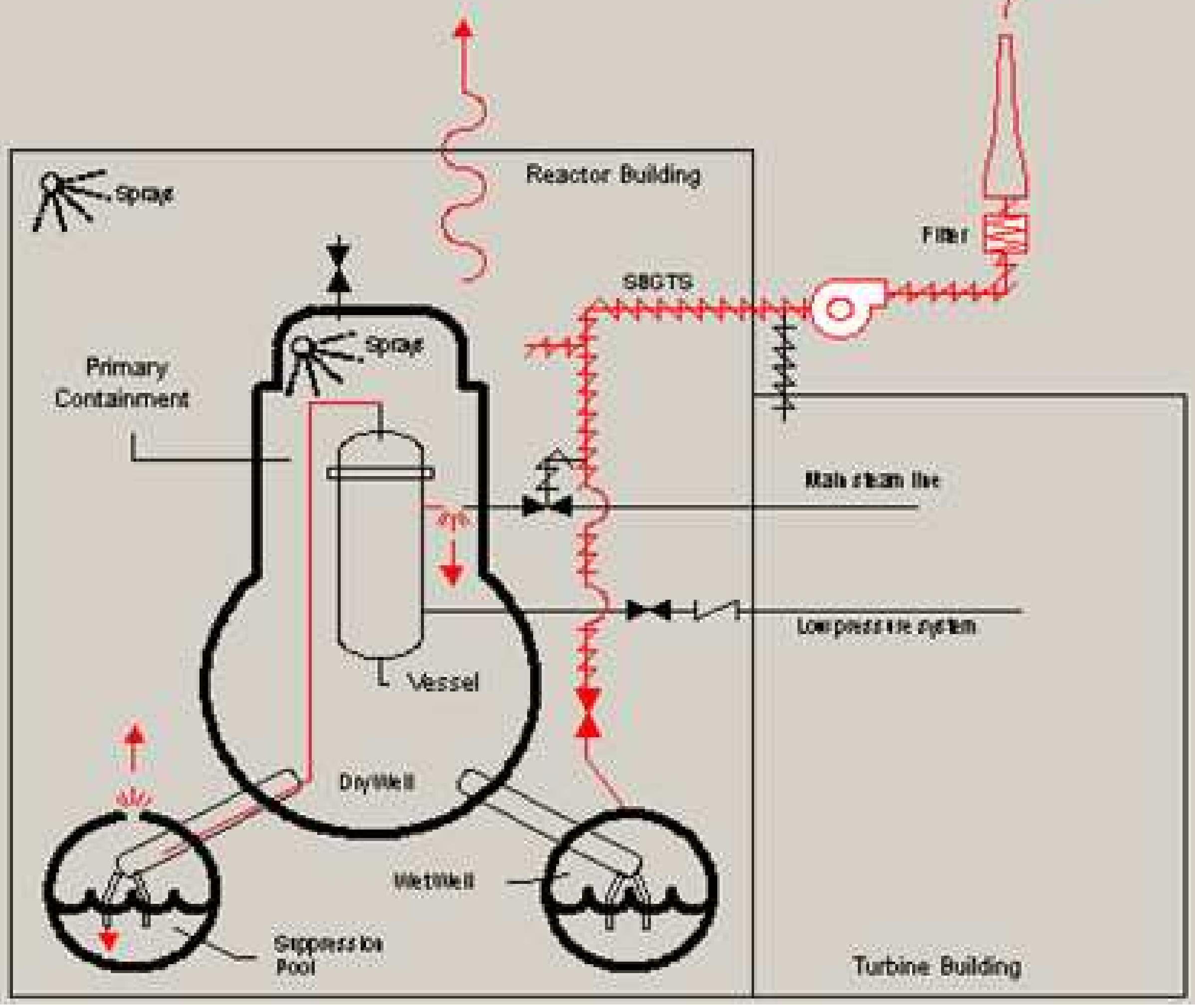


Bypass secondary containment



SOURCE TERM DEVELOPMENT: RELEASE PATHWAYS

Through the wet well



SOURCE TERM DEVELOPMENT: CREDIBLE WORSE CASE SCENARIO

- Most conservative and credible projected plant condition based on available information as of 2011-03-12
- Units 1-3 incurred partial core meltdown
- Unit 4 spent fuel pool assumed to be uncovered indefinitely
- Iterative process
  - Several scenarios were assembled, compared against available data, verified (spot-check calculations), revised, etc.

SOURCE TERM DEVELOPMENT: CREDIBLE WORSE CASE SCENARIO

- Release pathway → bypass of primary containment (through wet well)
- Release based on reactor core time uncovered
  - Rector shutdown → 2011-03-11 at 05:46
  - Core uncovered → 2011-03-12 at 09:00
  - Core recovered → 2011-03-12 at 21:00
- Release events
  - 2011-03-12 → leak rate of 100 gal/min
  - 2011-03-13 → filters off

SOURCE TERM DEVELOPMENT: CWC SCENARIO SOURCE TERM

- Unit 1 is ~ half the size of Units 2 and 3
- Units 2 and 3 identical
- Unit 4 spent fuel pool contained a little over two cores
- Release of 65 isotopes calculated

Isotope	Unit 1 [Bq]	Unit (2+3) [Bq]	SFP 4 [Bq]	Total [Bq]
Cs-137	2.80E+16	2×5.50E+16	2.10E+17	3.48E+17
I-131	2.70E+17	2×5.30E+17	6.70E+13	1.33E+18

SOURCE TERM DEVELOPMENT: CWC SCENARIO DOSE

- 80 km from site circa March 12-15 (24 h)
- CWC (weather) → ***DIRECT TO TOKYO***
- Release from the Unit 4 spent fuel pool contributes 11 mSv TEDE (small contribution to thyroid dose or via inhalation)
- Reactor cores primary contributor to thyroid dose (500 mSv)

Unit 1	Unit 2	Unit 3	SFP 4	Total
100 mSv	200 mSv	200 mSv	11 mSv	511 mSv

SOURCE TERM CALCULATION: IS IT BOUNDING?

- HC-RPB shared data from CTBTO monitoring station JPP38 at Takasaki (200 km away) $\rightarrow$ allowed us to zero-in on CWC
- ***CTBTO – Comprehensive Test Ban Treaty Organisation (ctbto.org)***
- JPP38 measurements confirmed that the ***SEVERITY*** of the radiological release was captured by our CWC

SOURCE TERM CALCULATION: IS IT BOUNDING?

	Ratio of model calculations to JPP38 measurements (HC-RPB)				
Isotope	U2 core melt, via wet well	U2 core melt, via bypass	SFP 4 drained, direct	U2 100% clad failure, via bypass	U2 100% clad failure, via wet well
Te-132	0.5	1.4	2.0E-11	3.4E-9	0.0
I-131	1.1	3.6	0.0016	7.7	0.8
I-132	0.2	0.9	5.0E-11	0.5	0.2
I-133	1.1	4.3	0.0	7.9	1.0
Xe-133	14.6	12.2	1.40E-05	15.2	19.2
Cs-134	1.8	5.7	17.5	12.4	1.2
Cs-136	1.1	3.3	0.0318	7.0	0.7
Cs-137	1.5	4.6	25.8	1.0	1.0

SOURCE TERM CALCULATION: SUPPLEMENTAL VERIFICATION

- NISA released dose rate measurements from within containment
- RASCAL can use containment radiation monitor readings to estimate core condition

Unit and date	Wet well monitor	RASCAL core melt estimate
Unit 1 (March 24, 17:00)	26 Sv/h	28%
Unit 2 (March 12, 13:00)	180 Sv/h	100%

SOURCE TERM SUMMARY

- Severity of accident captured in terms of radiological releases
- Conservative (simple) dose rate estimates based on CWC source term sufficient to trigger initial 80 km EZ (Health Canada guidelines)
- CWC source term provided to EC-CMC for detailed atmospheric modelling
  - Assess impact on Canadian West Coast
  - Plume arrived ~ March 19 (as predicted)

SOURCE TERM SUMMARY

- The postulated source term was the most CWC scenario
- CWC was bounding with respect to observed releases shortly after event
- Initial 80 km EZ in agreement with international partners (USNRC, UKONR)
- EZ status continuously being re-evaluated by the Government of Canada (CNSC/HC/EC/DFAIT/PS)

CURRENT PLANT STATUS

- Core-cooling and circulation system
  - Additional system being installed in parallel to existing one
    - Should allow faster clean up of basement water
    - Higher rate of water injection likely to reduce core temperatures
- Reactor building covers
  - Unit 1 targeted for September completion
  - Units 2-4 currently on-hold
- Nitrogen injection installed on all Units
- Spent fuel pool closed-loop cooling
  - Established for Units 2-4
  - Unit 1 by end of the week

Canada's Nuclear Regulator

PART III – CNSC REGULATORY PATH FORWARD

Canadian Nuclear Safety Commission
Commission canadienne de sûreté nucléaire

Canada

ESTABLISHMENT OF CNSC JAPAN TASK-FORCE – MANDATE

- Review submissions from licensees who have been directed under the NSCA 12(2) orders – ***ALL LICENSEES HAVE RESPONDED***
- Assess technical and operational information from the events at the Fukushima Daiichi NPP and identify high-level lessons learned
- Develop recommendations for short-term and long-term measures to recommend whether design or operational modifications (including supporting research) are needed
- Determine priorities for implementation of corrective actions
- Develop recommendations (as appropriate) for potential changes to CNSC regulatory requirements, inspection programmes, and policies

ESTABLISHMENT OF CNSC JAPAN TASK-FORCE – FOCUS

- External hazards which could impact Canadian NPPs (initiating events)
- Plant response up to severe core damage (assuming failed accident mitigation)
- Severe accident mitigation and management
- On-site and off-site emergency response
- Regulatory requirements review

REVIEW OF THE SAFETY CASES

- Focus on verify capabilities to mitigate
  - Beyond design basis events including station blackout
  - Internal and external flooding
  - Other events concurrent with a seismic event
- Verification of defence-in-depth strategies and measures to:
  - Minimise frequency of abnormal operations and failures
  - Limiting the progression of an accident to within design basis
  - Control severe plant conditions
  - Mitigate radiological consequences
- Emergency management procedures of the NPP

Canada's Nuclear Regulator

CNSC CCSN

THANK YOU

kiitos תודה

merci शुक्रिया grazie

asante

谢谢 danke terima kasih

köszönöm

ありがとう ďakujem

спасибо شكرا ขอบคุณคุณ

gracias diolch yn fawr

hvala 감사합니다

cảm ơn bạn