High Burnup Fuel Source Term Accident Analysis
Boiling-Water Reactor Follow-On Calculations

ACRS Radiation Protection And Nuclear Materials Subcommittee Briefing

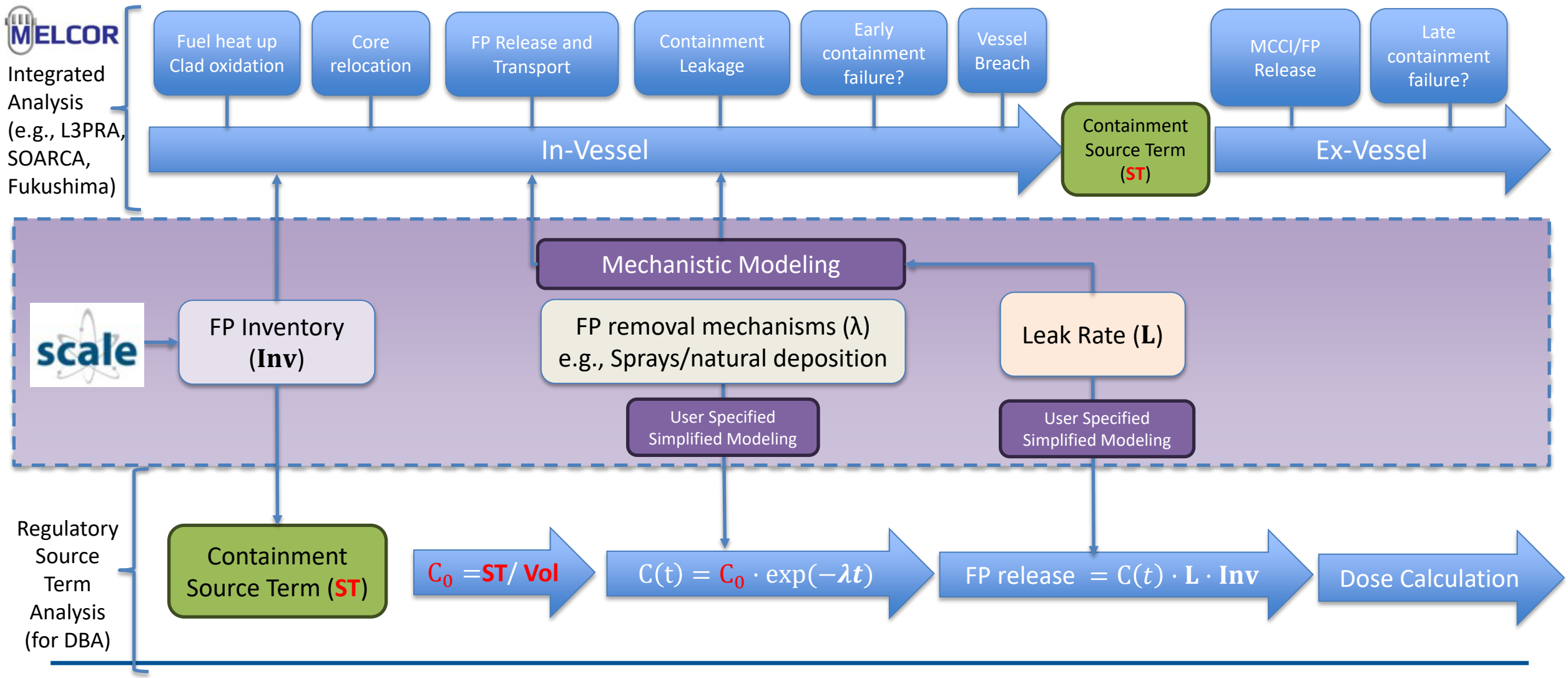
November 16, 2023

Shawn Campbell and Michael Salay
Fuel & Source Term Code Development Branch
Division of Systems Analysis
Office of Nuclear Regulatory Research

Background and Motivation

- *The High Burnup (HBU) Peer Review panelists commented on the potential impact of the suppression pool on the containment source term.*
- *Table 5-16 of SAND2023-01313 provides the boiling-water reactor (BWR) containment release fractions including and excluding the suppression pool.*
- *Supplemental investigations following the peer review in BWRs:*
  - *Investigate fission product concentration variation between different regions of the reactor system and containment since some scenarios and pathways bypass the suppression pool (e.g., main steam line).*
  - *Modified the two (Peach Bottom, Grand Gulf) full-scale BWR input decks to better capture aerosol behavior in the containment and steam line.*
  - *Performed a set of BWR source term calculations.*

Source Term Methodology



U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Illustration of BWR Modeling Practices

Area with refined modeling

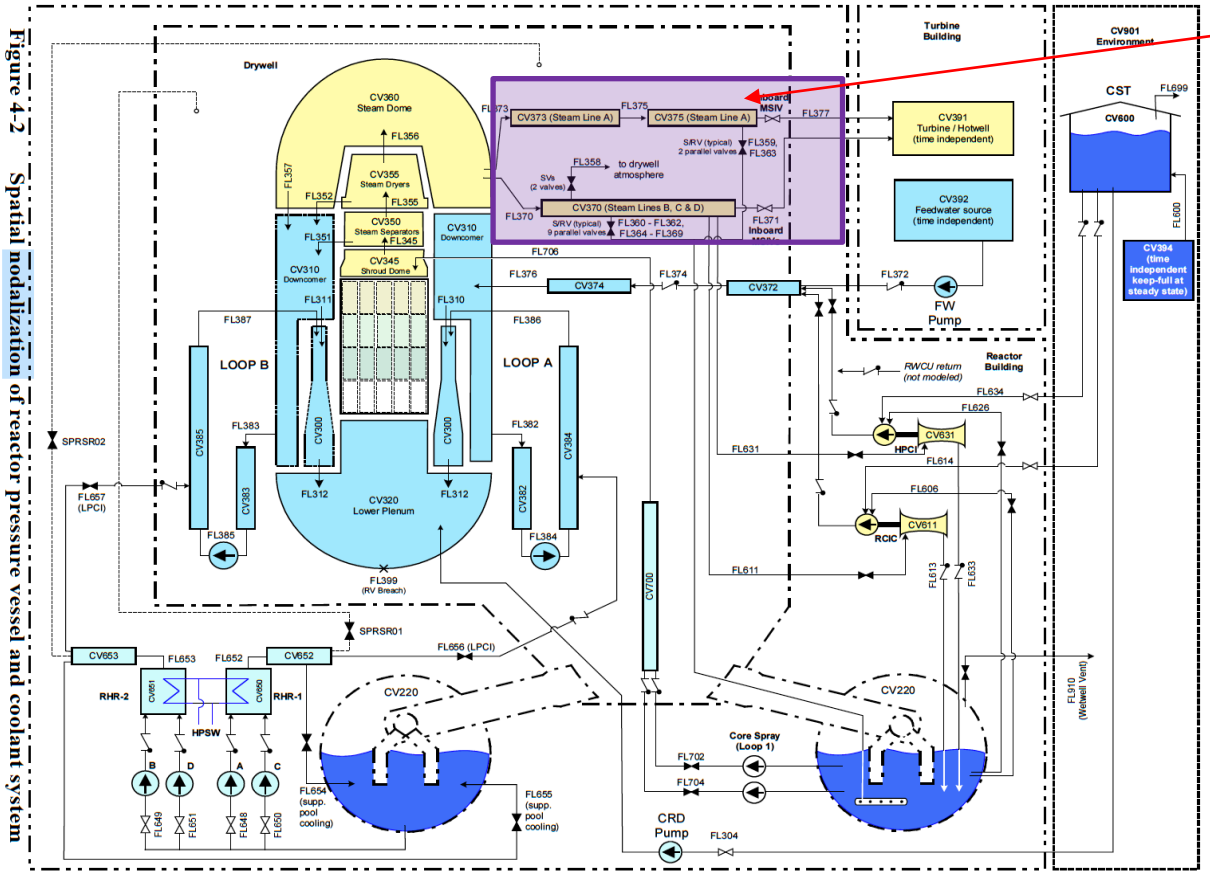
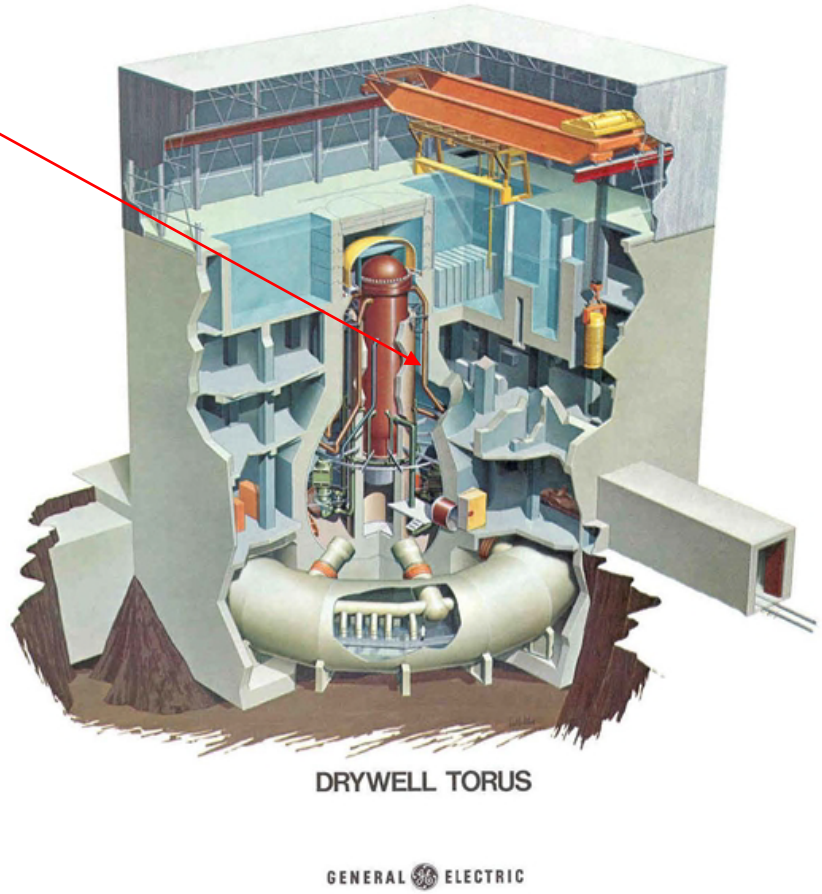


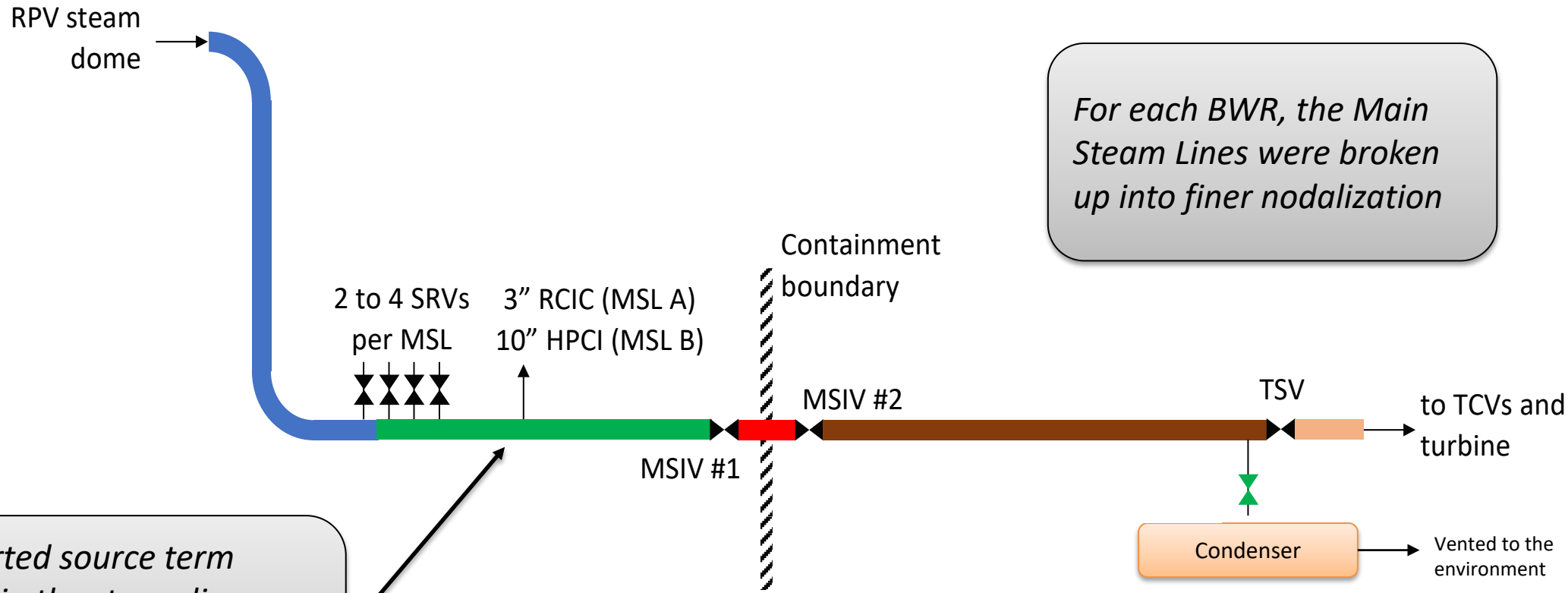
Figure 4-2 Spatial nodalization of reactor pressure vessel and coolant system

Peach Bottom



U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

New BWR Main Steam Line (MSL) Modeling



For each BWR, the Main Steam Lines were broken up into finer nodalization

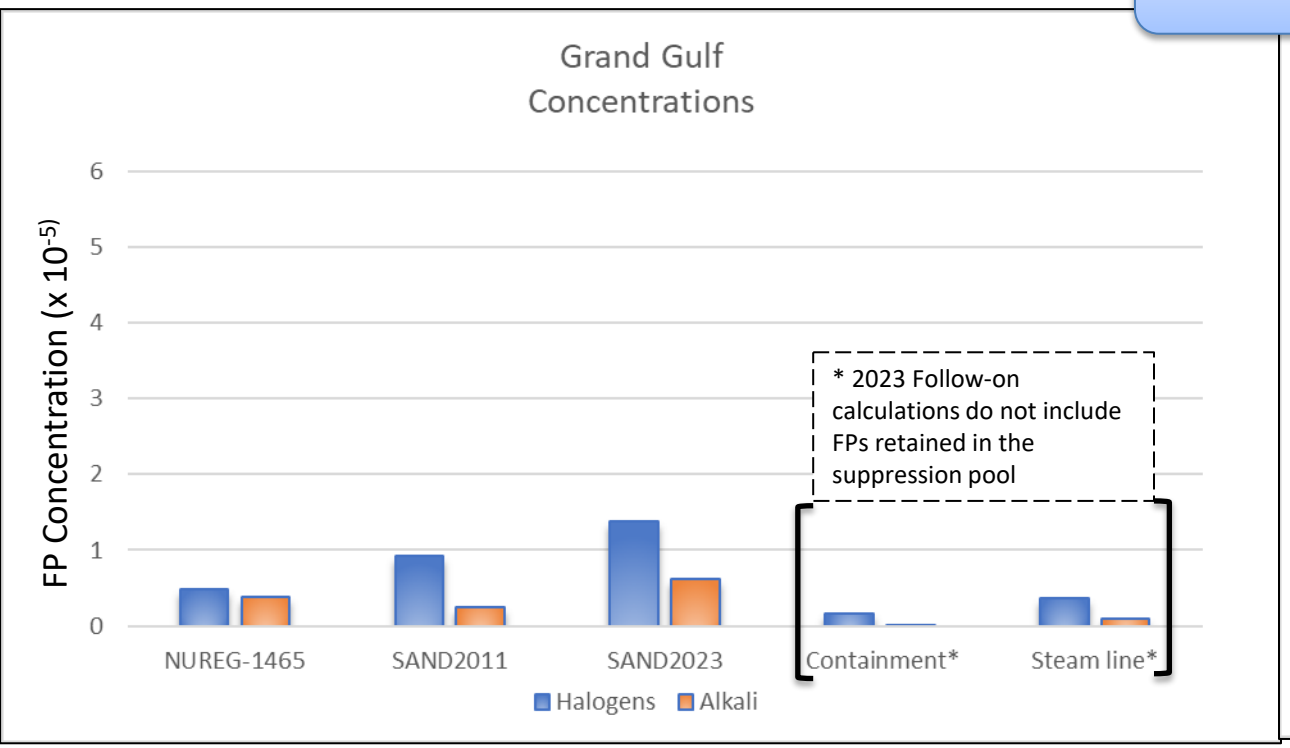
The reported source term fractions in the steam line are averaged airborne fission products in the green portion.

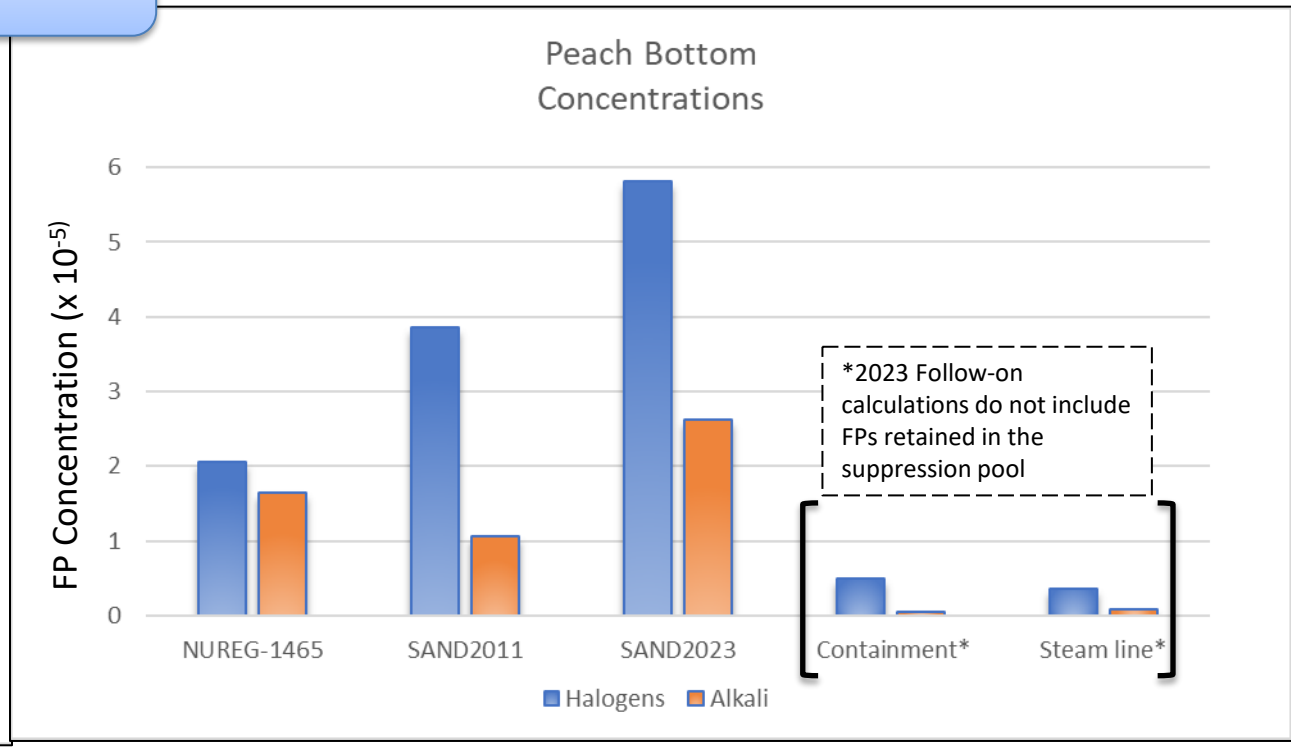
BWR Source Term (ST) Inventory Fractions – Early In-Vessel

Radionuclide Group	RG1.183 (rev0)	RG1.183 (rev1)	SAND2023	Pool (SAND2023 Table 5-16)	Containment (SAND2023 Table 5-16)	Steam Line (*Preliminary* Follow-on Calcs)
Noble Gases	9.50E-01	9.60E-01	9.50E-01	0.00E+00	9.50E-01	1.1E-03
Halogens	2.50E-01	5.40E-01	7.10E-01	6.50E-01	6.00E-02	5.1E-05
Alkali Metals	2.00E-01	1.40E-01	3.20E-01	3.10E-01	6.00E-03	1.3E-05
Te Group	5.00E-02	3.90E-01	5.60E-01	5.20E-01	3.80E-02	2.7E-05
Ba/Sr Group	2.00E-02	5.00E-03	5.00E-03	4.70E-03	3.00E-04	2.4E-07
Ru Group	3.00E-03	2.70E-03	6.00E-03	6.00E-03	7.40E-06	2.4E-07
Mo Group	3.00E-03	3.00E-02	1.20E-01	1.20E-01	1.00E-04	3.0E-06
Lanthanides	2.00E-04	<1.0e-6	<1.0e-6	<1.0e-6	<1.0e-6	1.0E-11
Ce Group	5.00E-04	<1.0e-6	<1.0e-6	<1.0e-6	<1.0e-6	8.4E-12

BWR Example Fission Product (FP) Concentrations (C_0)

C_0 = **ST**/ **Vol**





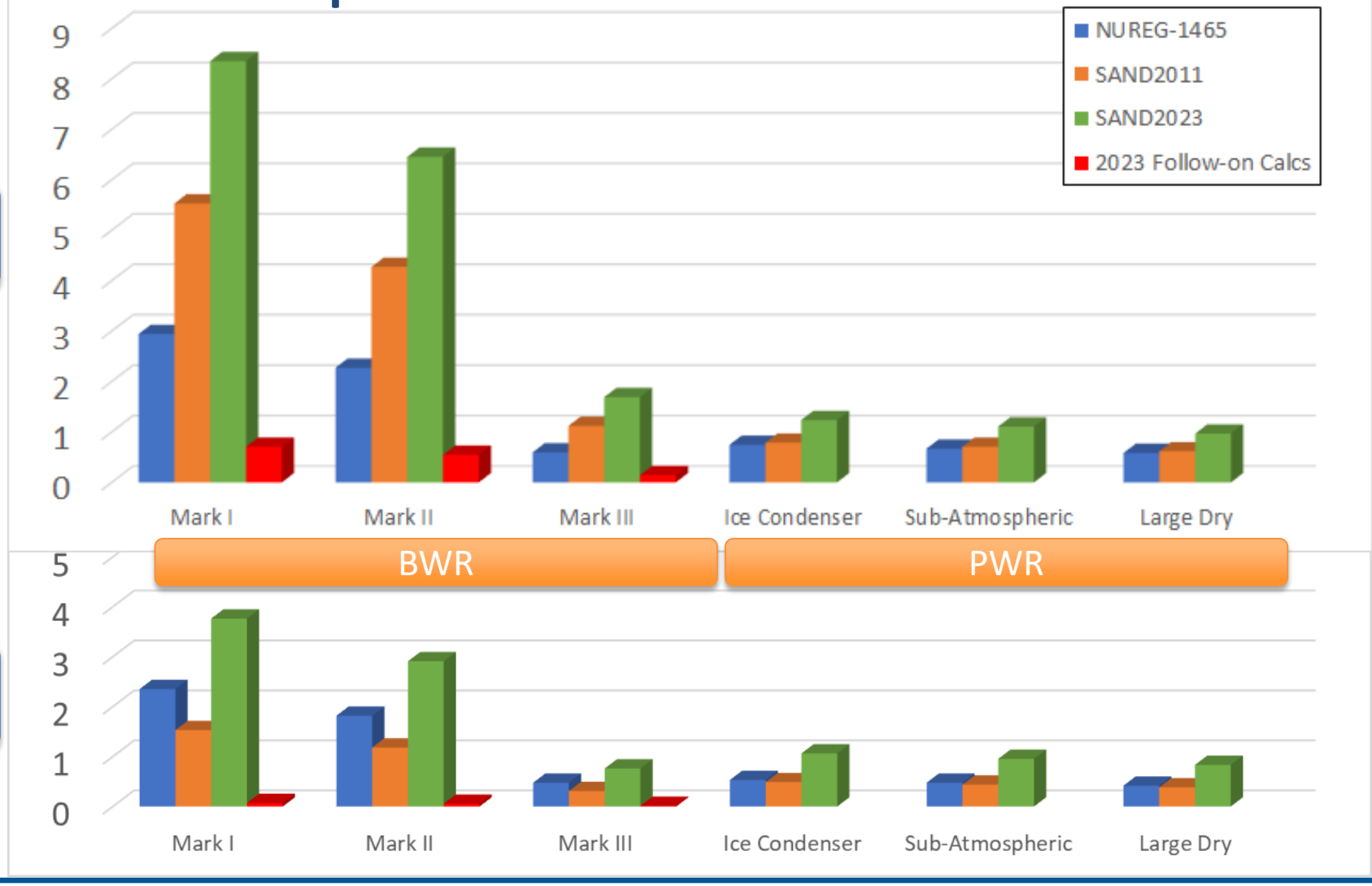
U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

BWR/PWR Example Containment Concentrations

Halogen (Iodine) x 1E-5

$C_0 = ST/Vol$

Alkali Metals (Cesium) x 1E-5



2023 Follow-on calculations do not include FPs retained in the BWR suppression pool

Typical containment volumes from *Figure 4.1-1 in NUREG/CR-6042, Rev. 2*

Example HBU Inventories

Radionuclide Group	BWR (Bq)	BWR (%) –> HBU	PWR (Bq)	PWR (%) –> HBU
Halogens (I)	3.54E19	<1%	2.53E19	<1%
Alkali Metals (Cs)	4.46E18	+7%	3.09E18	+5%
Chalcogen (Te)	1.16E19	<1%	8.35E18	<1%
	GE14 10x10	GE14 10x10	W 17x17	W 17x17
Core Avg. end of cycle BU (MWd/MTU)	36.2	41.4	43.5	48.3
Avg. Assembly discharge BU (MWd/MTU)	52.6	58.0	60.7	71.6
Initial Enrichment (%)	4.45	5.30	4.65	5.25
Power (MWt)	4016	4016	2893	2893
Cycle Length (months)	24	24	18	24

Conclusions and Next Steps

- Refined modeling provides better estimation of fission product distribution in the steamline.
  - Concentration in the steam line is distinct from that of containment.
- Significant retention of fission products were predicted in the suppression pool.
- Preliminary investigation of fission product inventories show limited effect for high burnup/high-assay low-enriched uranium (HBU/HALEU)fuels.
- Potential application of MELCOR to inform better estimates of fission product removal mechanisms in the simplified tools for regulatory applications and analysis where appropriate.

Backup Slides

Acronyms

Bq	Becquerel
BWR	boiling-water reactor
DBA	design-basis accident
FP	fission product
GE	General Electric
HALEU	high-assay low-enriched uranium
HBU	high burnup
HPCI	high pressure coolant injection
MSIV	main steam line isolation valve
MSL	main steam line
GWd/MTU	gigawatt-days per metric ton of uranium
MWt	Megawatt thermal
PWR	pressurized water reactor
RCIC	reactor core isolation cooling
RG	(NRC) regulatory guide
RPV	reactor pressure vessel
SOARCA	State-of-the-Art Reactor Consequence Analyses
SRV	safety relief valve
ST	source term
TCV	turbine control valve
TSV	turbine stop valve
W	Westinghouse

Table 5-16 **Derived BWR release fractions including and excluding the suppression pool inventory for all core variations (60 GWd/MTU, 80 GWd/MTU, LEU and HALEU).**

	Gap Release		Early In-vessel		Total (end of 72 hours)	
Release Category	Including Suppression Pool Inventory	Excluding Suppression Pool Inventory	Including Suppression Pool Inventory	Excluding Suppression Pool Inventory	Including Suppression Pool Inventory	Excluding Suppression Pool Inventory
Noble Gases	0.016	0.016	0.95	0.95	1	1
Halogens	0.005	1.30E-06	0.71	0.06	0.87	0.2
Alkali Metals	0.005	1.20E-06	0.32	0.006	0.35	0.039
Te Group	0.003	<1.0e-6	0.56	0.038	0.78	0.26
Ba/Sr Group	0.0006	<1.0e-6	0.005	0.0003	0.048	0.042
Ru Group	<1.0e-6	<1.0e-6	0.006	7.40E-06	0.006	0.0001
Mo Group	1.90E-05	<1.0e-6	0.12	0.0001	0.13	0.002
Lanthanides	<1.0e-6	<1.0e-6	<1.0e-6	<1.0e-6	3.70E-05	3.60E-05
Ce Group	<1.0e-6	<1.0e-6	<1.0e-6	<1.0e-6	0.003	0.003