SAND2011-0128 Report on Source Term

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Topics

- Origin
- Previous containment source terms
- SAND2011-0128 Objective
- Source Term development process
- Summary of SAND 2011 Source Term
- Changes in Releases
- Choice of Sequences
- Comments by 2011 Peer Review panel

Origin

- **Footnote to 10 CFR 100.11(a) (Siting: Exclusion Area, Low population zone, …)**

"The fission product release assumed for these calculations should be based upon a major accident hypothesized for purposes of site analysis or postulated from consideration of possible accidental events, that would result in potential hazards not exceeded by those from any accident considered credible. Such accidents have generally been assumed to result in substantial meltdown of the core with subsequent release of appreciable quantities of fission products."

Origin: Defense in Depth

- This is a classic performance-based rule to evaluate the defense in depth provided by the containment:
  - Applicant hypothesizes a release of radioactivity to the containment
  - Considering the design basis leak rate, and engineered safety features (but not ECCS) assesses the dose magnitude at the site boundary, control room and low population zone.

Origin: Interface with Risk-informed Regulation

- “Structural” defense in depth
  - What protections are afforded to the public health and safety even if low probability events occur and there is a major release of radioactivity from the reactor core.

Previous Containment Source Terms

- TID-14844 (1962)
  - Based on furnace heating of irradiated fuel chips
  - Instantly available in the containment at the start of an accident
- NUREG-1465 (1995) (& RG1.183 rev 0)
  - Result of post-Three Mile Island Accident severe-accident research effort (>$0.5b)
    - Source Term Code Package (STCP)
    - Developed alongside NUREG-1150 – Risk Analysis for Five Nuclear Plants
  - Separation of radionuclides into chemical groups that behave similarly
  - Timing and release fractions of chemical groups in different phases:
    - gap release, in-vessel release, ex-vessel, late in-vessel (revaporization).
    - First two phases used in RG1.183
  - Aggregate of results of simulation of representative set of unmitigated accident sequences
  - Based on analyses of plants with fuel used to burnups < 40 GWd/t
    - Regulatory limit is 62 GWd/t
    - Rim effect and changes in pellet/clad interactions found for burnups in excess of about 45 GWd/t

Objective of SAND2011-0128

- Define a “representative” source term to the containment for the evaluation of defense-in- depth capabilities:
  - Must be characteristic of accidents involving melting of a substantial fraction of the reactor core with HBU or MOX fuel
  - Not to be deliberately bounding
  - HBU result generically applicable to PWRs or BWRs
  - MOX result specific to Catawba
  - Not necessary to be the result of a self-consistent accident sequence
- Conform as closely as possible to the structure of the NUREG-1465 Source Term

Containment Source Term Development

PIRT process identified FP release behavior as major unkown for MOX and HBU fuel

Experimental Basis

Clad burst timing

Melt Progression Behavior

Fission Product Release

Gas Generation Rate

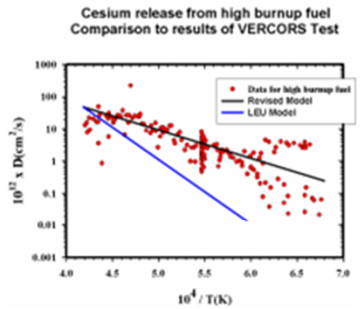
Fission Product Transport

Etc…

Oxidation Rate

MELCOR

Models



Accident Analysis for Range of Accident Scenarios

Scenario #1

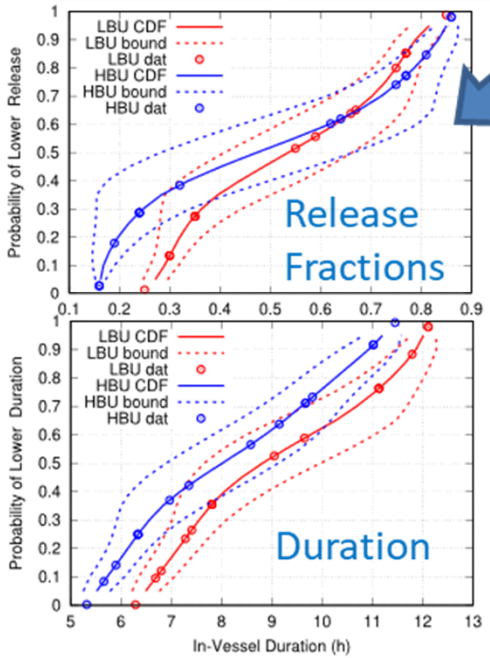
Scenario #2

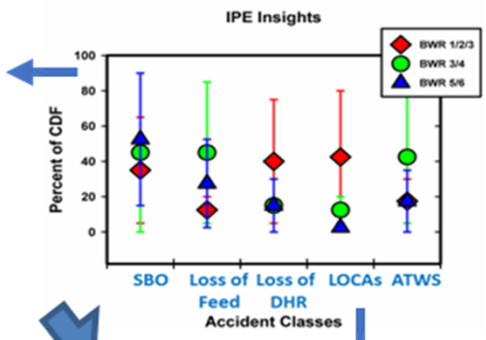
Scenario #3

Scenario #4

Scenario #5

Scenario #6





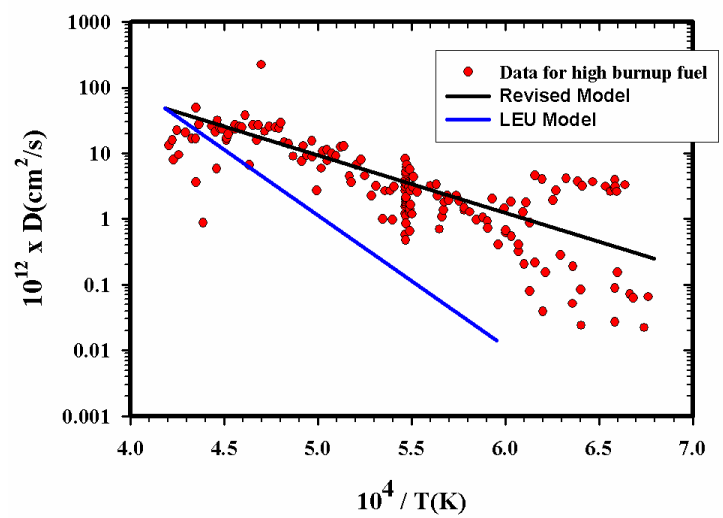
Synthesize sequence-specific timings and release fractions to representative table

Design Basis Source Term

Fission Product class	Gap 0.5 hr	In-vessel 1.3 hr	Ex-vessel 2 hr	Late 10 hr
Noble Gases	5%	95%	~0	~0
Iodine, bromine	5%	35%	25%	1%
Cesium	5%	25%	35%	1%
Tellurium	~0	5%	25%	0.5%
Ba, Sr	~0	2%	10%	~0
Ru, Mo, Pd, etc.	~0	0.25%	0.25%	~0
Lanthanides	~0	0.02%	0.5%	~0
Cerium group	~0	0.05%	0.5%	~0

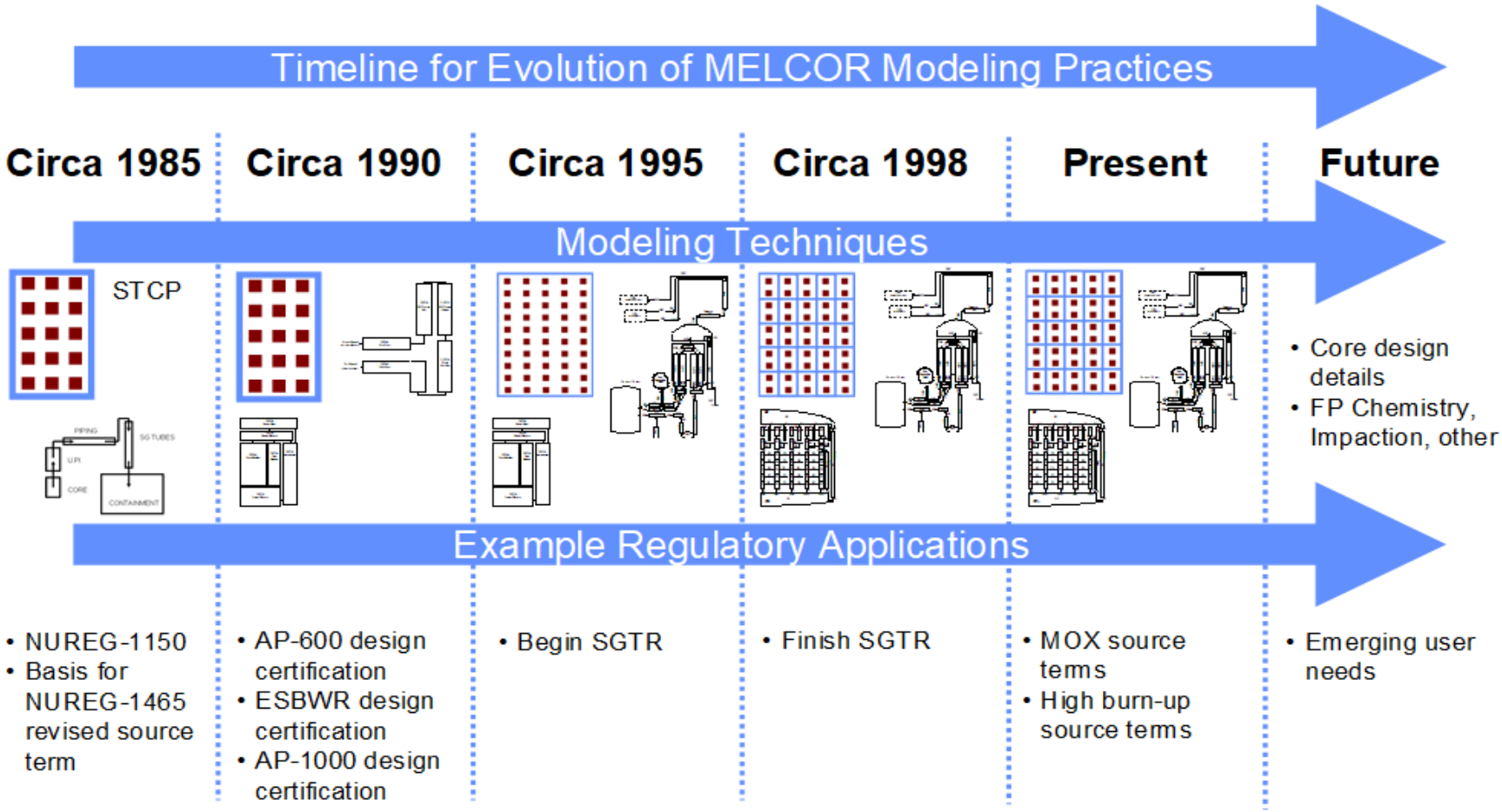
Summary of HBU Source Term

- NRC sponsored analysis at Sandia National Laboratories (SNL) to calculate source terms for low burnup and high burnup fuel (SAND2011-0128)
  - LBU: 26-38 GWD/MTU discharge burnup, which varied depending on the plant analyzed
  - HBU: 59 GWD/MTU max assembly-averaged discharge burnup (~ 62 GWD/MTU peak rod-averaged burnup)
- SNL calculations used MELCOR 1.8.5 for accident progression and ORIGEN for radionuclide and decay heat inventories
  - Cs diffusion coefficient
    - LBU based on Phebus FPT (fuel at 23 GWD/MTU)
    - HBU based on VERCORS test RT-6 (fuel at 72 GWD/MTU)



Sandia National Laboratories, "Accident Source Terms for LWR NPPs using High-Burnup or MOX Fuel," SAND2011-0128, 2011 (ADAMS Accession Number ML20093F003)

Evolution of Core Modeling – Major Effect



SAND2011-0128 Overall Findings

- Little difference between durations of release phases and release fractions for HBU and LBU, or MOX and LEU
- Major differences from NUREG-1465 attributed to improved understanding of
  - Core degradation modeling
  - Radionuclide chemistry under accident condition

Fission Product Release Fractions

- Substantially greater validation data available for the quantities of noble gases, iodine, cesium, and tellurium released under molten fuel conditions
  - PHEBUS-FP, VERCORS, VERDON, and others
- Experimental evidence indicates that tellurium will not be chemically bound to the Zircaloy cladding, as assumed in NUREG–1150
  - The peer review committee concludes that the larger release fractions for the tellurium group appear to be warranted.

BWR Results (SAND2011-0128)

	Gap Release			In-vessel Release		
Duration	0.16	0.20	0.5	8.0	8.8	1.5
Release Fractions	HBU	LBU	NUREG 1465	HBU	LBU	NUREG 1465
Noble Gases (Kr, Xe)	0.008	0.008	0.05	0.96	0.96	0.95
Halogens (I)	0.002	0.003	0.05	0.47	0.54	0.25
Alkali Metals (Cs)	0.002	0.003	0.05	0.13	0.14	0.20
Alkaline Earths (Ba)	-	-	-	0.005	0.005	0.02
Tellurium Group	0.002	0.003	-	0.39	0.39	0.05
Molybdenum	-	-	-	0.02	0.03	0.0025
Noble Metals	-	-	-	0.0027	0.0026	0.0025
Lanthanides	-	-	-	1.4E-7	2.0E-7	2.0E-4
Cerium Group	-	-	-	1.3E-7	1.6E-7	5.0E-4

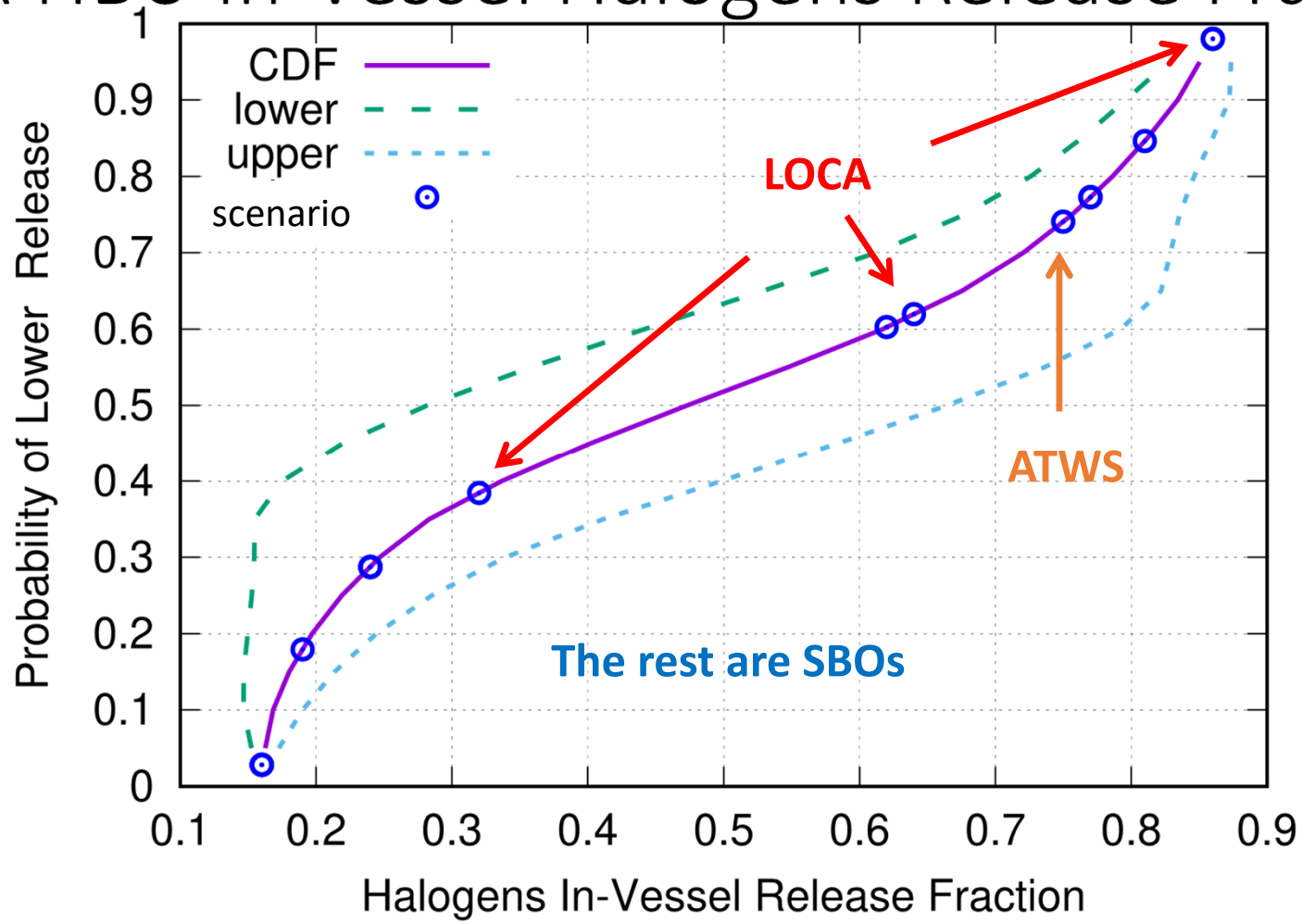
PWR Results (SAND2011-0128)

	Gap Release			In-vessel Release		
Duration	0.22	0.33	0.5	4.5	5.3	1.5
Release Fractions	HBU	LBU	NUREG 1465	HBU	LBU	NUREG 1465
Noble Gases (Kr, Xe)	0.017	0.022	0.05	0.94	0.85	0.95
Halogens (I)	0.004	0.007	0.05	0.37	0.30	0.35
Alkali Metals (Cs)	0.003	0.005	0.05	0.23	0.23	0.25
Alkaline Earths (Ba)	0.0006	0.0014	-	0.004	0.004	0.02
Tellurium Group	0.004	0.007	-	0.30	0.26	0.05
Molybdenum	-	-	-	0.08	0.10	0.0025
Noble Metals	-	-	-	0.006	0.006	0.0025
Lanthanides	-	-	-	1.5E-7	1.1E-7	2.0E-4
Cerium Group	-	-	-	1.5E-7	1.1E-7	5.0E-4

Choice of Sequences

- Accidents analyzed included station blackout (SBO) accidents, transients involving the loss of injection or loss of decay heat removal, Anticipated Transient Without Scram (ATWS), and breaks in the reactor coolant system.
- When combined, the accidents consider nearly all of the core damage frequency based on the results of Individual Plant Examinations (IPEs) documented in NUREG–1560
- Larger fraction of SBO sequences
  - Representative of greater set of sequences

BWR HBU In-Vessel Halogens Release Fraction



CDF = Cumulative Distribution Function

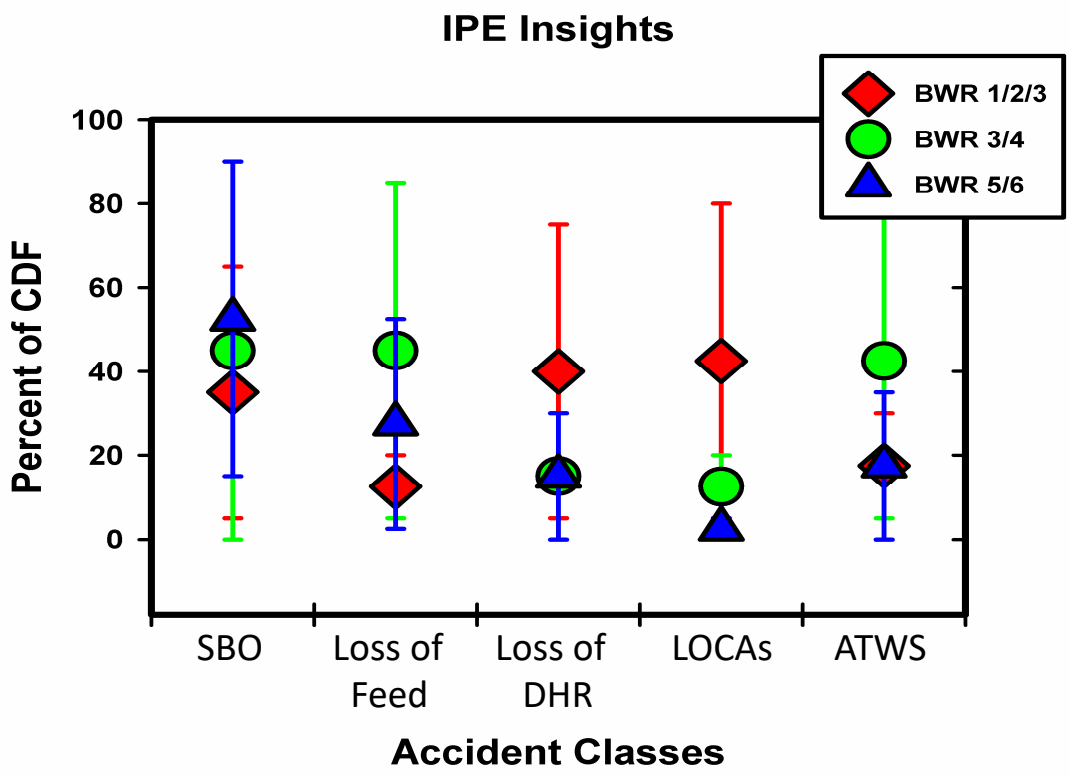
BWR Dominant Sequences (IPEs)

Peach Bottom

Initiator	CDF	%
LOCA	0.44×10^{-6}	10
ATWS	0.32×10^{-6}	8
Loss of offsite power	0.49×10^{-6}	11
Transient	3.02×10^{-6}	70
Coverage = 98% of CDF = 5.34×10^{-5}		

Grand Gulf

Initiator	CDF	%
LOCA	0.38×10^{-6}	2
ATWS	0.05×10^{-6}	0.3
Station Blackout	7.45×10^{-6}	43
Transient	9.34×10^{-6}	54
Coverage = 99% of CDF = 1.72×10^{-5}		



CDF = Core Damage Frequency

Suppression Pool Scrubbing

- Consistent with prior regulatory positions, all radionuclides that reach containment are considered part of the source term
  - Typical licensing/siting source term calculations involve a generic, rather than sequence-specific, source term
  - Uncertainties in accident sequence
  - Uncertainties in scrubbing conditions (e.g. pool saturation at time of release)
- This approach neglects scrubbing in Suppression Pool (SP)

SAND2011-0128 Peer Review*

- "The proposed source term satisfies the regulatory requirements of RG 1.183 pertaining to attributes of an acceptable alternative accident source term"
- Change in release fraction
  - The changes between the NUREG–1465 source terms result predominantly from advances in modeling and not from differences introduced by using MOX fuel or extensions to the burnup range.
  - The proposed source terms are more realistic than those provided in NUREG–1465 in terms of the timing, chemical forms, and release fractions; plutonium release fractions may be underestimated, but do not significantly impact the final source term.
- Methodology
  - The representation of variabilities in release quantities and other characteristics associated with the proposed source terms are reasonable. However, there are significant uncertainties in release quantities and species for iodine, which are currently being investigated.
- Choice of sequences
  - The peer review committee finds that this spectrum of accidents is sufficient to satisfy the following stated attributes of an acceptable alternative accident source term: "The accident source term must be expressed in terms of times and rates of appearance of radioactive fission products released into containment, the types and quantities of the radioactive species released, and the chemical forms of iodine released. "
- Tellurium
  - The peer review committee concludes that the larger release fractions for the tellurium group appear to be warranted.

***"PEER REVIEW OF ACCIDENT SOURCE TERMS FOR LIGHT-WATER NUCLEAR POWER PLANTS USING HIGH-BURNUP AND MIXED OXIDE FUEL," ERI/NRC 11-211, ML12005A043, December 2011**

Questions & Discussion

How did we do?

Link to NRC meeting feedback form:

https://feedback.nrc.gov/pmfs/feedback/form?meetingcode=20220575

Abbreviations

- ATWS Anticipated Transient Without Scram
- Ba barium
- BWR boiling-water reactor
- CDF core damage frequency
- CDF cumulative distribution function
- Cs cesium
- DHR decay heat removal
- FPT (Phebus) Fission Product Test
- GWD gigawatt days
- HBU high burnup (fuel)
- IPE individual plant examinations
- I Iodine
- Kr krypton
- LBU low burnup (fuel)
- LOCA loss of coolant accident
- MTU metric tons uranium
- MOX mixed oxide (fuel)
- PWR pressurized water reactor
- SBO station blackout
- SNL Sandia National Laboratories
- SGTR steam generator tube rupture
- Xe xenon