EVOLUTION OF SOURCE TERM DEFINITION AND ANALYSIS

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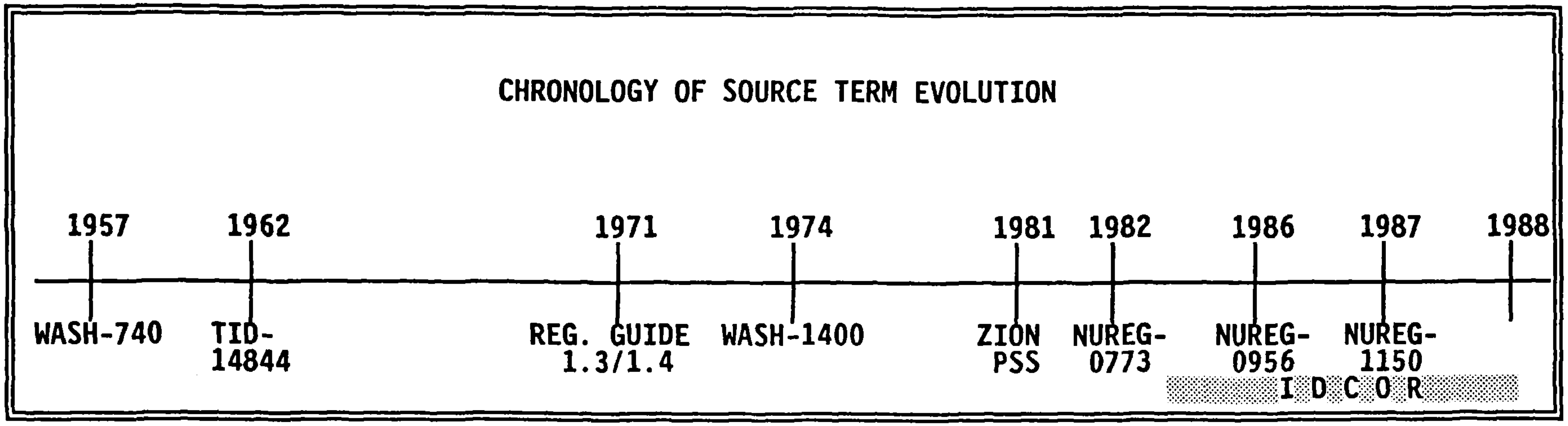
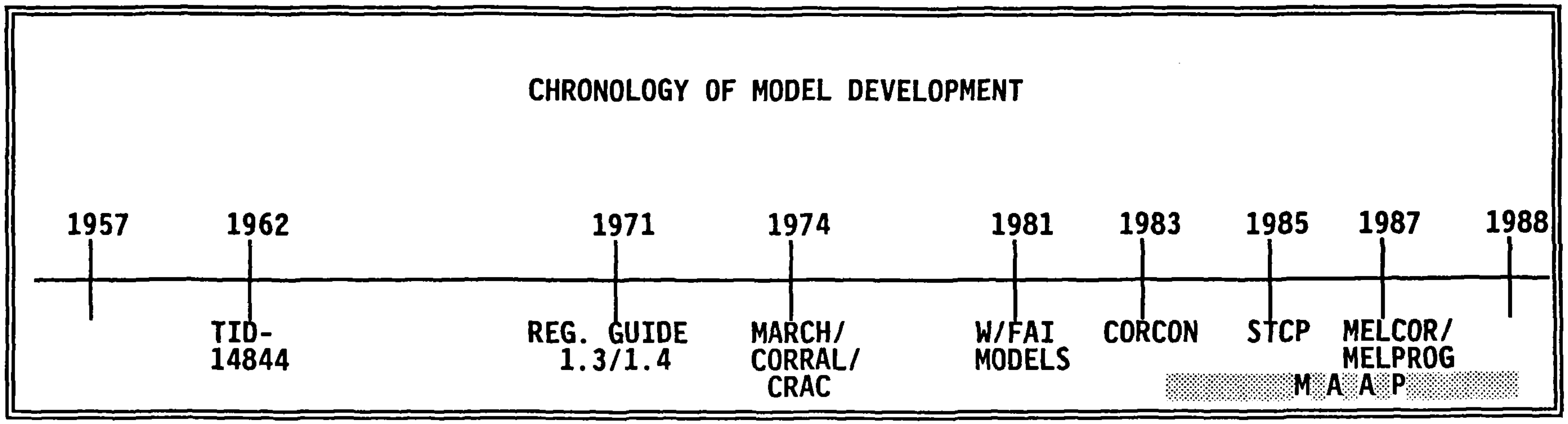
PURPOSE

- PROVIDE AN OVERVIEW OF THE EVOLUTION OF ACCIDENT FISSION PRODUCT RELEASE ANALYSIS METHODOLOGY AND RESULTS

- PROVIDE AN OVERVIEW OF THE IMPLEMENTATION OF SOURCE TERM ANALYSIS IN REGULATORY DECISIONS


CHRONOLOGY OF SOURCE TERM EVOLUTION
1957
1962
1971
1974
1981
1982
1986
1987
1988
WASH-740
TID-14844
REG. GUIDE 1.3/1.4
WASH-1400
ZION PSS
NUREG-0773
NUREG-0956
NUREG-1150
I D C O R


CHRONOLOGY OF MODEL DEVELOPMENT
1957
1962
1971
1974
1981
1983
1985
1987
1988
TID-14844
REG. GUIDE 1.3/1.4
MARCH/ CORRAL/ CRAC
W/FAI MODELS
CORCON
STCP
MELCOR/ MELPROG
M A A P

WASH-740 (1957)

- FIRST SEVERE ACCIDENT ASSESSMENT

- DEFINE 3 HAZARD STATES

  - MAJOR DAMAGE TO FUEL CLADDING (10^{-2} TO 10^{-4} PER YEAR)
  - CORE MELT WITH EFFECTIVE CONTAINMENT; NO RELEASES (10^{-3} TO 10^{-4} PER YEAR)
  - CORE MELTDOWN WITH CONTAINMENT FAILURE (10^{-5} TO 10^{-9} PER YEAR)

- ANALYZED RELEASE AND DISPERSION OF ALL REACTOR RADIOACTIVITY FOR HAZARD STATE 3

  - NO HOLDUP/REMOVAL OF RADIOACTIVITY IN THE PLANT SYSTEMS AND STRUCTURES

- PREDICTED "THOUSANDS" OF FATALITIES FROM LOW POWER REACTORS (e.g., 700 MW THERMAL)

- NOT <u>DIRECTLY</u> USED IN REGULATORY DECISION MAKING

  - IMPLIED NEED FOR A STRONG CONTAINMENT STRUCTURE

TID-14844 (1962)

- SEVERE ACCIDENT STUDY TO DETERMINE PLANT SITTING REQUIREMENTS
- FIRST ANALYTICAL METHODOLOGY FOR USE IN PLANT DESIGN AND REGULATORY DECISION MAKING; NON-MECHANISTIC ACCIDENT PROGRESSION
- INSTANTANEOUS RELEASE TO CONTAINMENT IS SPECIFIED AS:
  - 100% NOBLE GASES
  - 50% IODINES (VAPOR FORM)
  - 1% SOLIDS
- NON-MECHANISTIC PLATE-OUT OF 50% OF IODINES ONTO CONTAINMENT SURFACES
- CONTAINMENT BUILDING LEAKAGE AT DESIGN RATE (0.1% PER DAY)
- OFFSITE DOSES CALCULATED FOR HYPOTHETICAL INDIVIDUAL; NO SHIELDING
- ESTABLISHES MINIMUM SITE BOUNDARY AND POPULATION CENTER DISTANCES

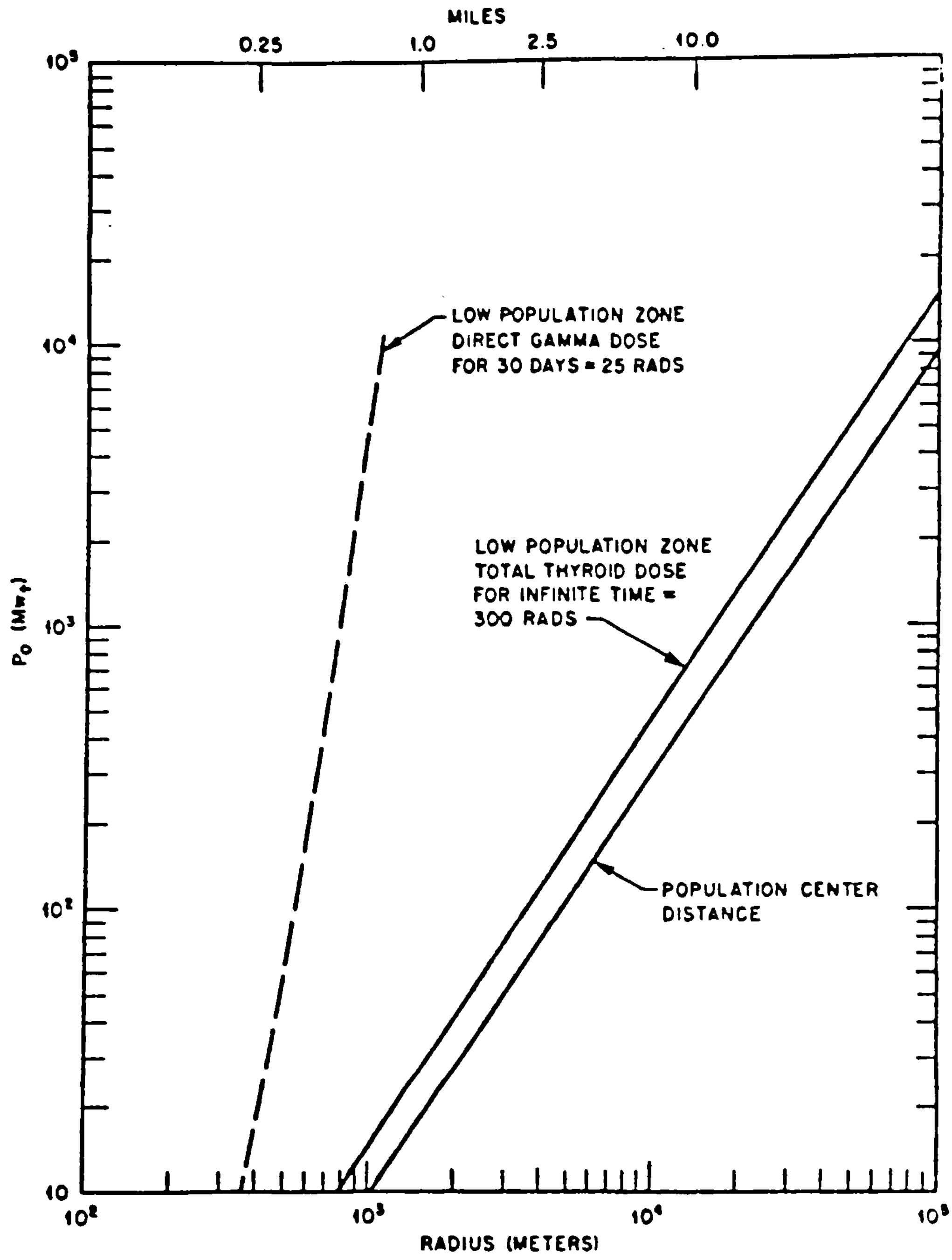


Figure 2. Population Radius Determination.

(FROM TID-14844)

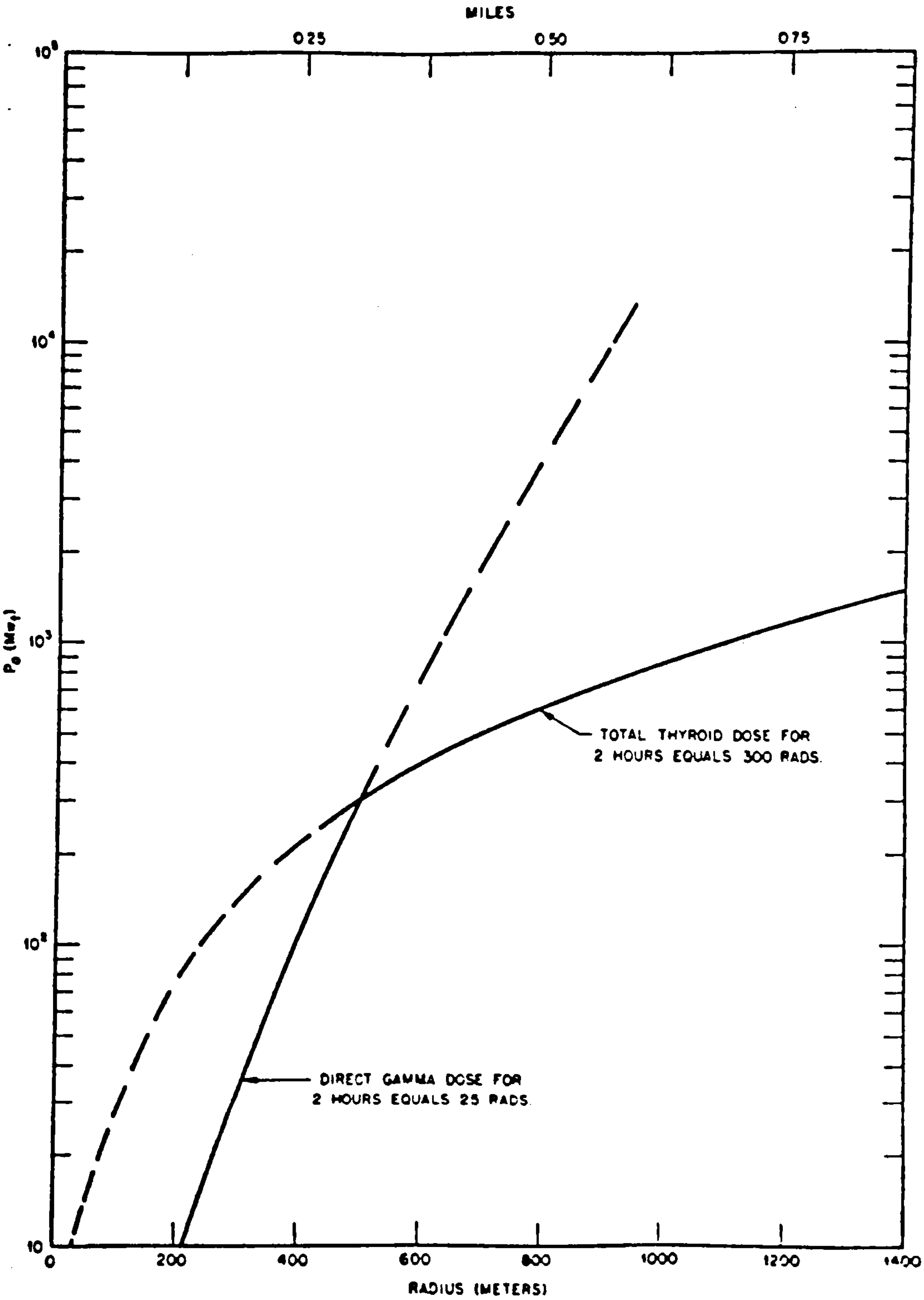


Figure 1. Exclusion Radius Determination.

(FROM TID-14844)

REGULATORY GUIDE 1.4 (1971)

- PROVIDES PERSCRIPTION FOR CALCULATING OFFSITE DOSES FOR MAXIMUM CREDIBLE ACCIDENT; NON-MECHANISTIC ACCIDENT PROGRESSION

- INSTANTANEOUS RELEASE TO CONTAINMENT IS SPECIFIED AS:

  - 100% NOBLE GASES
  - 50% IODINES IN VAPOR FORM (85-10-5 ELEMENTAL; ORGANIC; PARTICULATE)

- CREDIT FOR IODINE REMOVAL FOR PLATEOUT, CONTAINMENT SPRAYS AND FILTER SYSTEMS

- CONTAINMENT LEAKAGE AT DESIGN RATE FOR 24 HOURS; THEN ONE HALF DESIGN RATE

- USED IN THE U.S.A. FOR PLANT DESIGN BASIS AND SITTING (UP TO PRESENT TIME)

  - BASIS FOR SITE BOUNDARY AND POPULATION CENTER DISTANCES
  - BASIS FOR CONTAINMENT DESIGN FOR LEAK-TIGHTNESS
  - BASIS FOR CONTAINMENT SPRAY AND FILTRATION SYSTEMS

WASH-1400 (1974)

- FIRST MECHANISTIC TREATMENT OF ACCIDENT PROGRESSION
- USED REALISTIC BASES, FROM AVAILABLE EVIDENCE AND EXPERT OPTION
- ESTABLISHED 9 PWR AND 7 BWR CLASSES, OR BINS, OF FISSION PRODUCT RELEASES
  - RELATED TO MECHANISTIC ACCIDENT
  - RELATED TO PROBABILITY OF ACCIDENT PROGRESSION

TABLE 5-1 SUMMARY OF ACCIDENTS INVOLVING CORE

RELEASE CATEGORY	PROBABILITY per Reactor-Yr	TIME OF RELEASE (Hr)	DURATION OF RELEASE (Hr)	WARNING TIME FOR EVACUATION (Hr)	ELEVATION OF RELEASE (Meters)	CONTAINMENT ENERGY RELEASE (10^6 Btu/Hr)	FRACTION OF CORE INVENTORY RELEASED[a] Xe-Kr	Org. I	I	Cs-Rb	Te-Sb	Ba-Sr	Ru[b]	La[c]
PWR 1	$9x10^{-7}$	2.5	0.5	1.0	25	520[d]	0.9	$6x10^{-3}$	0.7	0.4	0.4	0.05	0.4	$3x10^{-3}$
PWR 2	$8x10^{-6}$	2.5	0.5	1.0	0	170	0.9	$7x10^{-3}$	0.7	0.5	0.3	0.06	0.02	$4x10^{-3}$
PWR 3	$4x10^{-6}$	5.0	1.5	2.0	0	6	0.8	$6x10^{-3}$	0.2	0.2	0.3	0.02	0.03	$3x10^{-3}$
PWR 4	$5x10^{-7}$	2.0	3.0	2.0	0	1	0.6	$2x10^{-3}$	0.09	0.04	0.03	$5x10^{-3}$	$3x10^{-3}$	$4x10^{-4}$
PWR 5	$7x10^{-7}$	2.0	4.0	1.0	0	0.3	0.3	$2x10^{-3}$	0.03	$9x10^{-3}$	$5x10^{-3}$	$1x10^{-3}$	$6x10^{-4}$	$7x10^{-5}$
PWR 6	$6x10^{-6}$	12.0	10.0	1.0	0	N/A	0.3	$2x10^{-3}$	$8x10^{-4}$	$8x10^{-4}$	$1x10^{-3}$	$9x10^{-5}$	$7x10^{-5}$	$1x10^{-5}$
PWR 7	$4x10^{-5}$	10.0	10.0	1.0	0	N/A	$6x10^{-3}$	$2x10^{-5}$	$2x10^{-5}$	$1x10^{-5}$	$2x10^{-5}$	$1x10^{-6}$	$1x10^{-6}$	$2x10^{-7}$
PWR 8	$4x10^{-5}$	0.5	0.5	N/A	0	N/A	$2x10^{-3}$	$5x10^{-6}$	$1x10^{-4}$	$5x10^{-4}$	$1x10^{-6}$	$1x10^{-8}$	0	0
PWR 9	$4x10^{-4}$	0.5	0.5	N/A	0	N/A	$3x10^{-6}$	$7x10^{-9}$	$1x10^{-7}$	$6x10^{-7}$	$1x10^{-9}$	$1x10^{-11}$	0	0
BWR 1	$1x10^{-6}$	2.0	2.0	1.5	25	130	1.0	$7x10^{-3}$	0.40	0.40	0.70	0.05	0.5	$5x10^{-3}$
BWR 2	$6x10^{-6}$	30.0	3.0	2.0	0	30	1.0	$7x10^{-3}$	0.90	0.50	0.30	0.10	0.03	$4x10^{-3}$
BWR 3	$2x10^{-5}$	30.0	3.0	2.0	25	20	1.0	$7x10^{-3}$	0.10	0.10	0.30	0.01	0.02	$3x10^{-3}$
BWR 4	$2x10^{-6}$	5.0	2.0	2.0	25	N/A	0.6	$7x10^{-4}$	$8x10^{-4}$	$5x10^{-3}$	$4x10^{-3}$	$6x10^{-4}$	$6x10^{-4}$	$1x10^{-4}$
BWR 5	$1x10^{-4}$	3.5	5.0	N/A	150	N/A	$5x10^{-4}$	$2x10^{-9}$	$6x10^{-11}$	$4x10^{-9}$	$8x10^{-12}$	$8x10^{-14}$	0	0

(a) A discussion of the isotopes used in the study is found in Appendix VI. Background on the isotope groups and release mechanisms is found in Appendix VII.

(b) Includes Mo, Rh, Tc, Co.

(c) Includes Nd, Y, Ce, Pr, La, Nb, Am, Cm, Pu, Np, Zr.

(d) A lower energy release rate than this value applies to part of the period over which the radioactivity is being released. The effect of lower energy release rates on consequences is found in Appendix VI.

WASH-1400 ADVANCES IN TECHNOLOGY

- MECHANISTIC TREATMENT OF FISSION PRODUCT RELEASES
  - CORE MELT
  - OXIDATION
  - VAPORIZATION
- MECHANISTIC TREATMENT OF CONTAINMENT FAILURES
  - OVERPRESSURE
  - STEAM EXPLOSION
  - HYDROGEN BURN
  - BASEMAT PENETRATION
- CODE DEVELOPMENT FOR SEVERE ACCIDENT ANALYSIS
  - MARCH
  - CORRAL
  - CRAC

WASH-1400 DEFICIENCIES (RETROSPECTIVE)

- ALL CORE MELT ACCIDENTS RESULT IN CONTAINMENT FAILURE
- SIMPLISTIC FISSION PRODUCT TRANSPORT DEPLETION MODELLING
- OTHERS OF LESSER IMPORTANCE

WASH-1400
REGULATORY IMPLEMENTATION

- LOW PROFILE UNTIL TMI-2 ACCIDENT

- POST-TMI-2:
  - BASIS FOR REGULATORY RESEARCH ON SEVERE ACCIDENTS
  - JCO FOR ZION/INDIAN POINT HIGH POPULATION DENSITY RISKS

ZION PROBABILISTIC SAFETY STUDY (1981)

- FIRST "INDUSTRY SPONSORED" ASSESSMENT OF SEVERE ACCIDENTS; IN RESPONSE TO JCO FOR HIGH POPULATION DENSITY SITES

- MAJOR ADVANCEMENTS IN TECHNOLOGY OF ACCIDENT PROGRESSION:

  - LOW PROBABILITY OF STEAM EXPLOSION

  - EXPERIMENTALLY DERIVED CORRELATION FOR HYDROGEN DEFLAGRATION

  - DETAILED REACTOR VESSEL FAILURE PHENOMENA DEVELOPMENT

    -- MODE OF VESSEL FAILURE
    -- DISPERSION OF CORE DEBRIS FROM REACTOR CAVITY
    -- CORE DEBRIS COOLABILITY

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ZION PROBABILISTIC RISK ASSESSMENT

- DEVELOPMENTS IN ACCIDENT PROGRESSION TECHNOLOGY IMPACTED SOURCE TERM ESTIMATES
  - SIGNIFICANTLY REDUCED PROBABILITY OF "EARLY" CONTAINMENT FAILURE VS. WASH-1400
  - TIME OF "LATE" CONTAINMENT FAILURE SIGNIFICANTLY EXTENDED VS. WASH-1400
  - NO "LATE" CONTAINMENT FAILURE PREDICTED FOR ACCIDENT SCENARIOS WITH CONTAINMENT HEAT REMOVAL AVAILABLE
- OVERALL RESULTS SHOWED THAT CONTAINMENT STRUCTURE IS EFFECTIVE IN REDUCING "RISK" BY A FACTOR OF 100 VS. WASH-1400

Table B-10

ZION

RADIOACTIVITY RELEASE FRACTIONS FOR SOURCE TERM CATEGORIES
(FRACTION OF CORE - INVENTORY RELEASE FROM CONTAINMENT)
FISSION PRODUCT CLASS

Designations For This Study	Org I	Iodine	Cs-Rb	Te-Sb	Ba-Sr	Ru	La	Xe-Kr
Z-1A/B	$6x10^{-3}$	0.7	0.1	0.35	0.05	0.21	$3x10^{-3}$	0.9
2	$7x10^{-3}$	0.7	0.5	.3	0.06	0.02	$4x10^{-3}$	0.9
2RV	$7x10^{-3}$	$1.4x10^{-2}$	$1.0x10^{-2}$	$6x10^{-3}$	$1.2x10^{-3}$	$4x10^{-4}$	$8x10^{-5}$	0.9
Z-3	$6x10^{-3}$	0.2	0.2	0.025	0.02	0.015	$3x10^{-3}$	0.8
4	$2x10^{-3}$	0.09	0.04	0.03	$5x10^{-3}$	$3x10^{-3}$	$4x10^{-4}$	0.6
Z-5A/B	$7x10^{-3}$	0.2	0.25	0.25	0.025	$1.5x10^{-2}$	$4x10^{-3}$	0.8
5	$2x10^{-3}$	0.03	$9x10^{-3}$	$5x10^{-3}$	$1x10^{-3}$	$6x10^{-4}$	$7x10^{-5}$	0.3
6	$2x10^{-3}$	$8x10^{-4}$	$8x10^{-4}$	$1x10^{-3}$	$9x10^{-5}$	$7x10^{-5}$	$1x10^{-5}$	0.3
7	$2x10^{-5}$	$2x10^{-5}$	$1x10^{-5}$	$2x10^{-5}$	$1x10^{-6}$	$1x10^{-6}$	$2x10^{-7}$	$6x10^{-3}$
8A	$1.7x10^{-4}$	$2.7x10^{-3}$	$5.0x10^{-6}$	$1.0x10^{-6}$	$7x10^{-7}$	$2x10^{-7}$	$2x10^{-8}$	$2.7x10^{-2}$
8B	$1.9x10^{-4}$	$1.6x10^{-5}$	$8x10^{-7}$	$1.5x10^{-7}$	$1x10^{-7}$	$3x10^{-8}$	$3x10^{-9}$	$2.7x10^{-2}$

<u>Notes:</u>

Z-1 - RSS Category 1 Source Modified for 25% rather than 50% fine particulate generation (affects Te & Ru only)

Z-3 - RSS Category 3 Source Modified for 25% rather than 50% fine particulate generation (affects Te & Ru only)

Z-5 - RSS Category 2 Source Term Modified for Short Term Spray Application.

ZION PROBABILISTIC RISK ASSESSMENT

- PROVIDED BASIS FOR REGULATORY DECISION ON CONTINUED PLANT OPERATION

- PROVIDED BASIS FOR TECHNICAL EXCHANGE BETWEEN NRC AND INDUSTRY

- REFOCUSED SOME NRC SEVERE ACCIDENT RESEARCH

NUREG-0773 (1982)

- SANDIA DEVELOPMENT OF SITTING SOURCE TERMS
  - BASED ON WASH-1400 WITH SOME ADJUSTMENTS

- USED BY NRC IN DEVELOPING OFFSITE EMERGENCY PLANNING CRITERIA IN NUREG-0396 AND NUREG-0654
  - 10 MILE PLUME EPZ
  - 50 MILE GROUND DEPOSITION EPZ

NUREG-0956 (1986)

- PROVIDES A REASSESSMENT OF SOURCE TERMS FOR SEVERE ACCIDENTS VS. WASH-1400 BY U.S. NRC

- INTRODUCES THE NRC "SOURCE TERM CODE PACKAGE" (STCP)

  - ORIGEN
  - MARCH
  - CORSOR
  - TRAPMELT
  - MERGE
  - CORCON
  - VANESA
  - NAUA, SPARC, ICEDF

- MAJOR IMPROVEMENTS IN FISSION PRODUCT MODELLING

  - FISSION PRODUCT CHEMISTRY
  - INTERACTION OF THERMAL HYDRAULICS AND FISSION PRODUCT BEHAVIOR

- "INTEGRATED PACKAGE" FOR SEVERE ACCIDENT ANALYSIS; BUT CUMBERSOME TO USE

NUREG-0956

- REFOCUSED NRC SEVERE ACCIDENT RESEARCH
- PROVIDED RATIONALE FOR DEVELOPMENT OF AN "INTEGRATED CODE" FOR THERMAL/HYDRAULIC AND FISSION PRODUCT BEHAVIOR
  - MELPROG
  - MELCOR
- USED AS BASIS FOR SOME REGULATORY INITIATIVES:
  - HYDROGEN CONTROL
  - NO CONTAINMENT VENTING
  - ACCIDENT MANAGEMENT

NUREG-1150 (1987)

- UPDATE OF REACTOR RISK VS. WASH-1400 FOR U.S. PLANTS (6 REFERENCE PLANTS)

- DRAFT REPORT BASED ON STCP RESULTS

- SIGNIFICANT PROBLEMS IN DRAFT REPORT IMPACTING SOURCE TERM ESTIMATES

  - EXPERT OPINION PROCESS
  - RELIANCE ON STCP
  - INTERPOLATION OF SOURCE TERM UNCERTAINTY

- FINAL REPORT (1988) WILL "ADDRESS" DEFICIENCIES

  - USE OF WIDE SPECTRUM OF EXPERTS
  - CONSIDERATION OF RESULTS OTHER THAN STCP

    -- MELPROG
    -- MELCOR
    -- MAAP

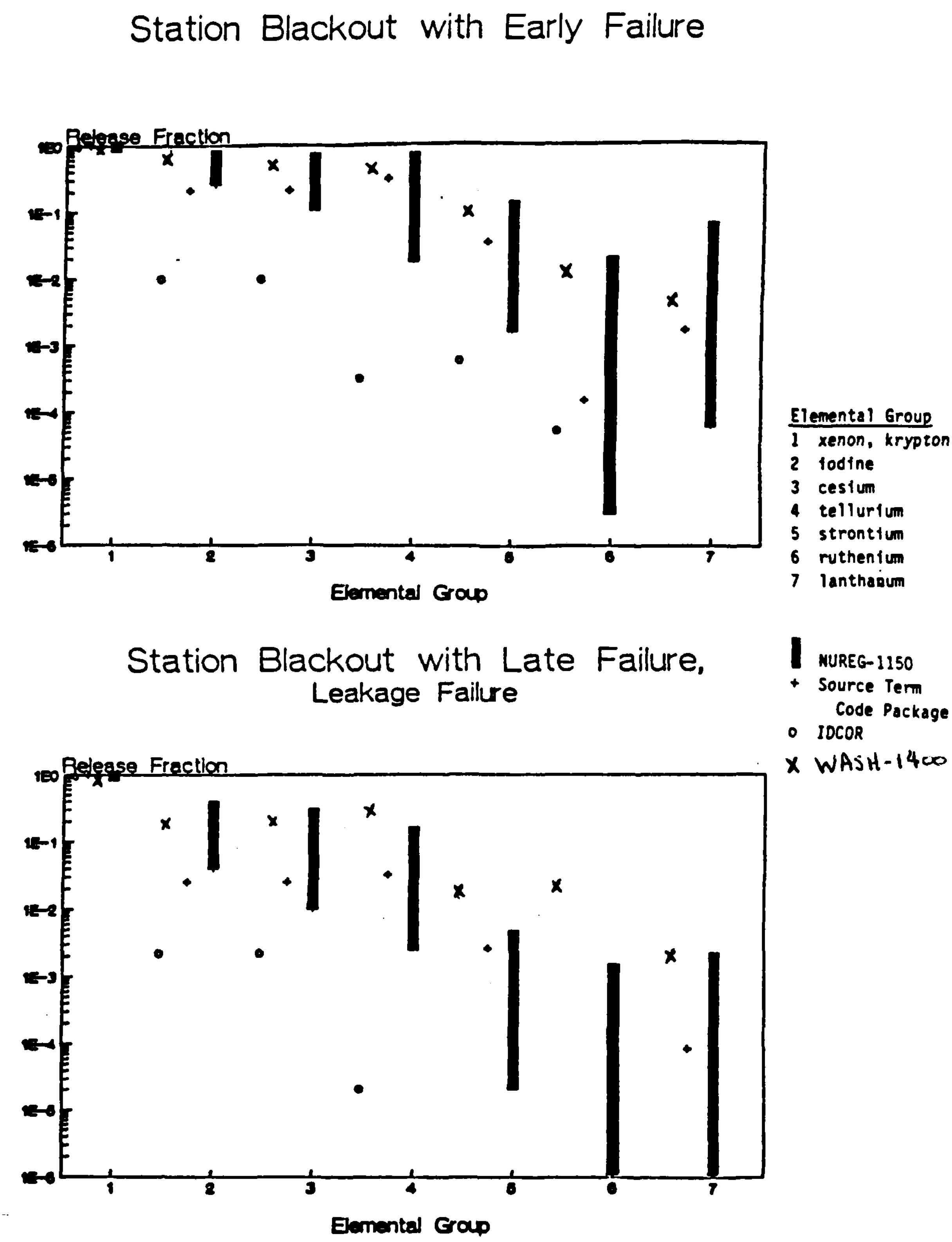

Figure 5.5 Comparison of results for station blackout scenarios at Zion

(FROM NUREG-1150)

IDCOR (1983 - 1988)

- MAJOR "INDUSTRY SPONSORED" RESEARCH AND DEVELOPMENT PROGRAM FOCUSED ON SEVERE ACCIDENT SOURCE TERMS

- SIGNIFICANT TECHNOLOGICAL ADVANCES

  - DEVELOPMENT OF FIRST INTEGRATED CODE TO MODEL THERMAL HYDRAULICS AND FISSION PRODUCT BEHAVIOR (MAAP CODE)

  - DEVELOPMENT OF REALISTIC FISSION PRODUCT PHYSICAL AND CHEMICAL MODELS

  - DEVELOPMENT OF REALISTIC CORE DEBRIS PHYSICAL AND CHEMICAL MODELS

  - DETAILED DOCUMENTATION FOR ALL MODELLING EFFORTS

IDCOR

- OVERALL RESULTS SHOW A SIGNIFICANT DECREASE IN FISSION PRODUCT RELEASES
  - LONG TIMES TO "LATE" CONTAINMENT FAILURES
  - SIGNIFICANT FISSION PRODUCT RETENTION IN FUEL, PRIMARY SYSTEM AND CONTAINMENT

ZION
TMLB' WITH A SEAL LOCA

ASSUMPTIONS:

CONTAINMENT FAILURE EVALUATION;
ANNULAR AREA, 579' TO 614'

CONTAINMENT FAILURE SIZE;
SUFFICIENT TO TERMINATE THE PRESSURIZATION

RESULTS (AT 45 HOURS, 13 HOURS AFTER CONTAINMENT FAILURE):

ISOTOPE	RELEASE FRACTION
Cs, I	.0017
Te, Sb	2 x 10-5
Sr, Ba	<1 x 10-5
Ru, Mo	<1 x 10-5

TIME OF RELEASE: 32 HOURS

Table 7.1

SUMMARY OF FRACTIONAL RADIONUCLIDE RELEASES TO THE ENVIRONMENT

	Fission Product Group				
Accident	Xe and Kr	Cs and I	Te	Sr and Ba	Ru and Mo
T_1QUV	1.0	7.3 E-5	3.2 E-5	$< 1 \times 10^{-5}$	$< 1 \times 10^{-5}$
AE	1.0	$< 1 \times 10^{-5}$	1.1 E-5	$< 1 \times 10^{-5}$	$< 1 \times 10^{-5}$
$T_{23}QW$	1.0	2.6 E-4	2.2 E-4	$< 1 \times 10^{-5}$	$< 1 \times 10^{-5}$
$T_{23}C$	1.0	7.6 E-4	7.5 E-4	$< 1 \times 10^{-5}$	$< 1 \times 10^{-5}$
BWR-4	0.6	5.0 E-3*	4.0 E-3	6.0 E-4	6.0 E-4

*Iodine release fraction is 0.8 E-4.
Cesium release fraction is 5.0 E-3.

Table 7.2

SUMMARY OF FISSION PRODUCT RELEASE FRACTIONS[(a)]

	Sequence				WASH-1400	
F.P. Group	TW	TC	S_1E	TQVW	BWR2[(b)]	BWR3[(c)]
Cesium Iodide	0.19	0.03	0.04	0.05	0.50, 0.90	0.10
Tellurium	0.11	0.06	0.06	0.06	0.30	0.30
Strontium	4×10^{-4}	1×10^{-4}	1×10^{-5}	8×10^{-5}	0.10	0.01
Ruthenium	6×10^{-4}	2×10^{-4}	2×10^{-5}	1×10^{-4}	0.03	0.02
Cesium Hydroxide	0.19	0.03	0.04	0.05	-	-
Time Release (hr)	42	13	23	18	-	-
Duration of Release (hr)	80	50	30	30	-	-

(a) Fraction of core inventory released to the environment.

(b) Containment failure prior to vessel failure; can be compared with (TW).

(c) Failure to scram or remove decay heat; can be compared with (TC, S_1E, TQVW).

IDCOR
CONTINUED TECHNOLOGY EVOLUTION

- BETWEEN 1983 AND PRESENT, THE IDCOR TECHNOLOGY HAS EVOLVED TO
  - ADVANCE PHENOMENA MODELLING
  - ADDRESS REGULATORY ISSUES

- NEW MODELS DEVELOPED BY IDCOR, OR OTHERS, AND IMPLEMENTED INTO MAAP IMPACT THE SOURCE TERM PREDICTIONS:
  - FISSION PRODUCT CHEMISTRY (e.g., Te)
  - REACTOR COOLANT SYSTEM NODALIZATION AND NATURAL CIRCULATION
  - AEROSOL PHYSICAL PHENOMENA

MAAP CODE MODEL EVOLUTION

	IDCOR T23.1Z TMLB'-δ_ℓ	MAAP T5.4 TMLB'-δ_ℓ	MAAP TMLB'-δ_ℓ
VERSON OF MAAP	1.0	2.0	3.0
TOP OF CORE UNCOVERED (HRS)	2.2	2.3	2.1
START OF FUEL MELT (HR)	3.0	N/A	2.9
VESSEL BREACH (HR)	3.8	3.4	4.0
CONTAINMENT OVER-PRESSURE FAILURE (HR)	32.0	27.9	34.1
TIME OF FISSION PRODUCT RELEASE (HR)	32.0	27.9	34.1
FISSION PRODUCT RELEASE FRACTIONS:			
Xe-Kr	1×10^{0}	1×10^{0}	---
I-Br	2×10^{-3}	3×10^{-5}	3×10^{-4}
Cs-Rb	2×10^{-3}	5×10^{-2}	---
Te-Sb	2×10^{-5}	2×10^{-4}	6.4×10^{-3}
Sr-Ba	$<1\times10^{-5}$	$<1\times10^{-5}$	4.0×10^{-5}
Ru-Mo	$<1\times10^{-5}$	1×10^{-2}	---

CONCLUSIONS

- ESTIMATES OF THE FISSION PRODUCE RELEASE TO ATMOSPHERE FOR CORE MELT ACCIDENTS (SOURCE TERM)
  - PROGRESSED FROM NON-MECHANISTIC TO DETAILED ACCOUNTING OF ACCIDENT SCENARIOS
  - PROGRESSED FROM SIMPLISTIC MODELLING TO DETAILED ACCOUNTING OF THERMAL HYDRAULICS AND PHYSICAL/CHEMICAL PROCESSES
  - PROGRESSED FROM CONSERVATIVELY HIGH ESTIMATES TOWARD MORE REALISTIC VALUES

- REGULATORY DECISIONS BASED ON SEVERE ACCIDENT CONSIDERATIONS:
  - CONTINUE TO BE DRIVEN BY ANALYSIS WITH "OLD" CONSERVATIVE TECHNOLOGY
  - ARE DRIVEN BY QUASI-POLITICAL INPUTS