중대사고와 PSA의 연계

2015.10.28

양준언

기존 발표

- 양준언, "리스크평가와 중대사고 분야의 연계 강화방안," 중대사고시 노심용융물 관리기술 및 국내 중대사고 정책·제도 추진 방향 워크숍, 2013.5

- 안광일, "중대사고 분야와 PSA 연계 방안," 2015 제8차 PSA 워크숍, 2015.3

목차

- PSA(Probabilistic Safety Assessment)란 무엇인가?
- PSA와 중대사고의 연결 부분
- PSA 분야가 중대사고 분야에 원하는 것

PSA(Probabilistic Safety Assessment)란 무엇인가?

리스크평가/리스크정보활용 & …

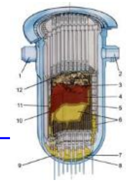
초기 사건

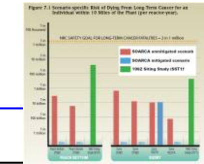
[기기 고장]

[인적 오류]

[자연 재해]

[인적 재해]





1단계 PSA: 노심손상빈도

	안전 계통 1	안전 계통 2	결과
빈도			OK
			OK
			노심 손상

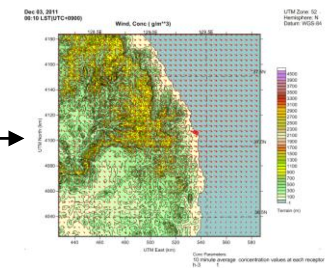
- 기기(펌프/밸브) 고장 (정비/보수)
- 인적 오류 (절차서)
- 공통원인 고장

2단계 PSA: 격납건물 파손빈도 및 방사성 물질 누출량

	중대 사고	격납 건물	결과
			OK
			OK
			방사성 물질 누출

- Leak/Rupture
- STC 별 방출량

3단계 PSA: 방사성 물질 확산 및 피폭

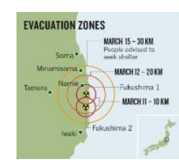


- Fatality
- 환경 오염

절차서 개선

설계/기기 개선

중대사고 전략 개선 (EOP-SAMG-EDMG)



비상 대응개선

면진 설비

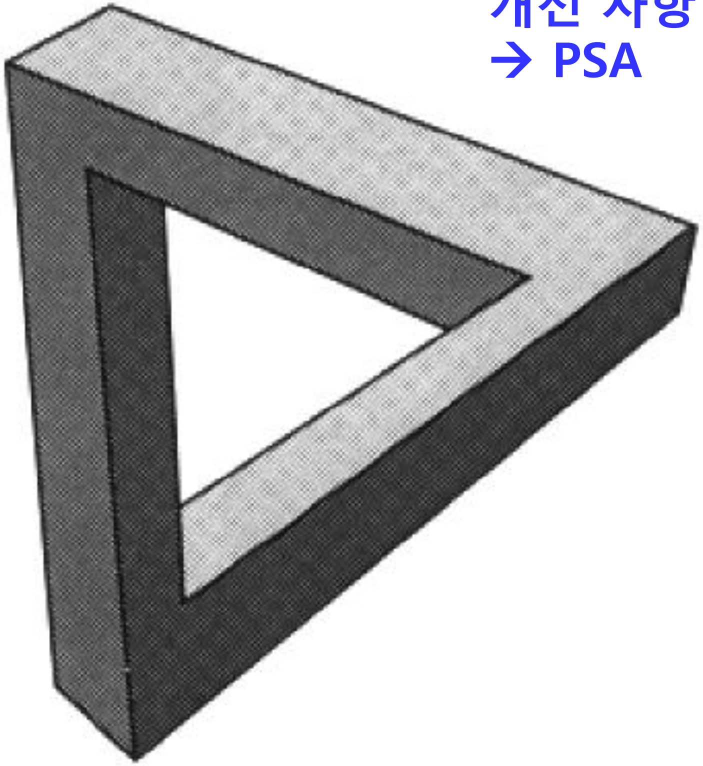
물리적 방호 (핵심구역)

미국 PSA의 역사

- Although using risk analysis to help with decision making has a number of advantages, it took over twelve years from the publication of the Reactor Safety Study in 1975 until the NRC produced Generic Letter 88-20 in 1988, formally enabling the use of PRAs in the industry. There are several reasons for this delay;
  - foremost was the lack of understanding of just what a risk assessment was, and how it would be used.
  - Second, most engineers tend to stick with the methods that they learned, and through the 1960s and 1970s, risk analysis education was not widespread and the NRC was dominated by staff comfortable and familiar with a deterministic/structuralist school.
  - Finally, the administration of the NRC was not comfortable with the concept, partly because of the initial reception of the Reactor Safety Study and partly due to the idea behind the quote from Max Planck in the introduction, "A new scientific truth triumphs not because its opponents become convinced and finally see the light, [but] rather, because they eventually die and a new generation is born which is familiar with the new concepts".
- This statement might be too black and white, but for the most part adequately describes how the use of PRA became acknowledged as useful and later as fundamental by the NRC—engineers and scientists familiar with the process had to move into positions of power and policy-making to facilitate the use of PRAs

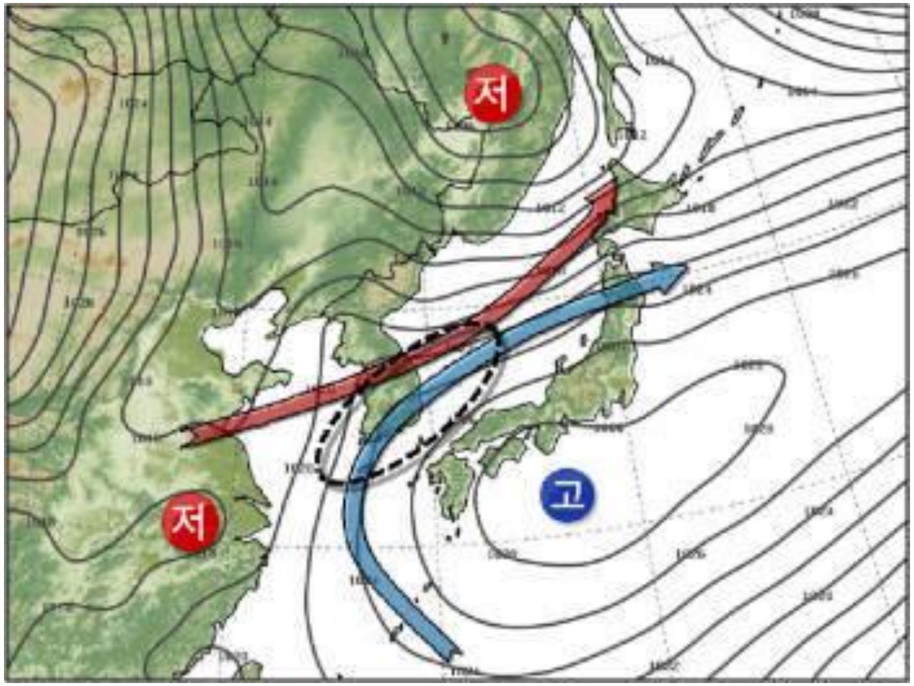
"Reliability Engineering and System Safety 89 (2005) 271–285"

PSA: Integration



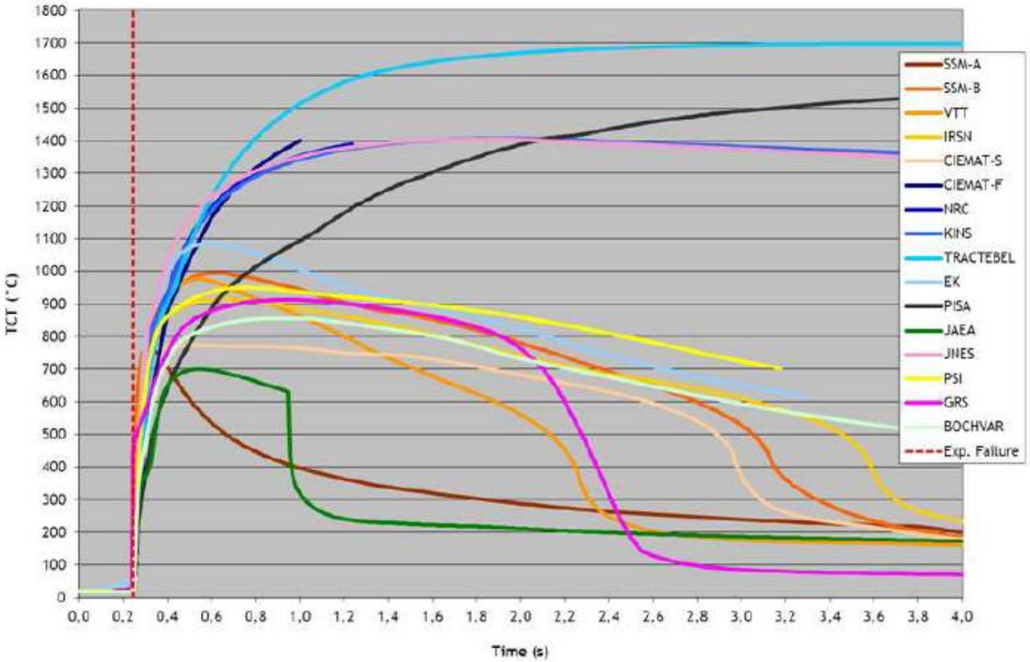
종합적 관점의
개선 사항 도출
→ PSA

P(확률)



Degree of Belief...

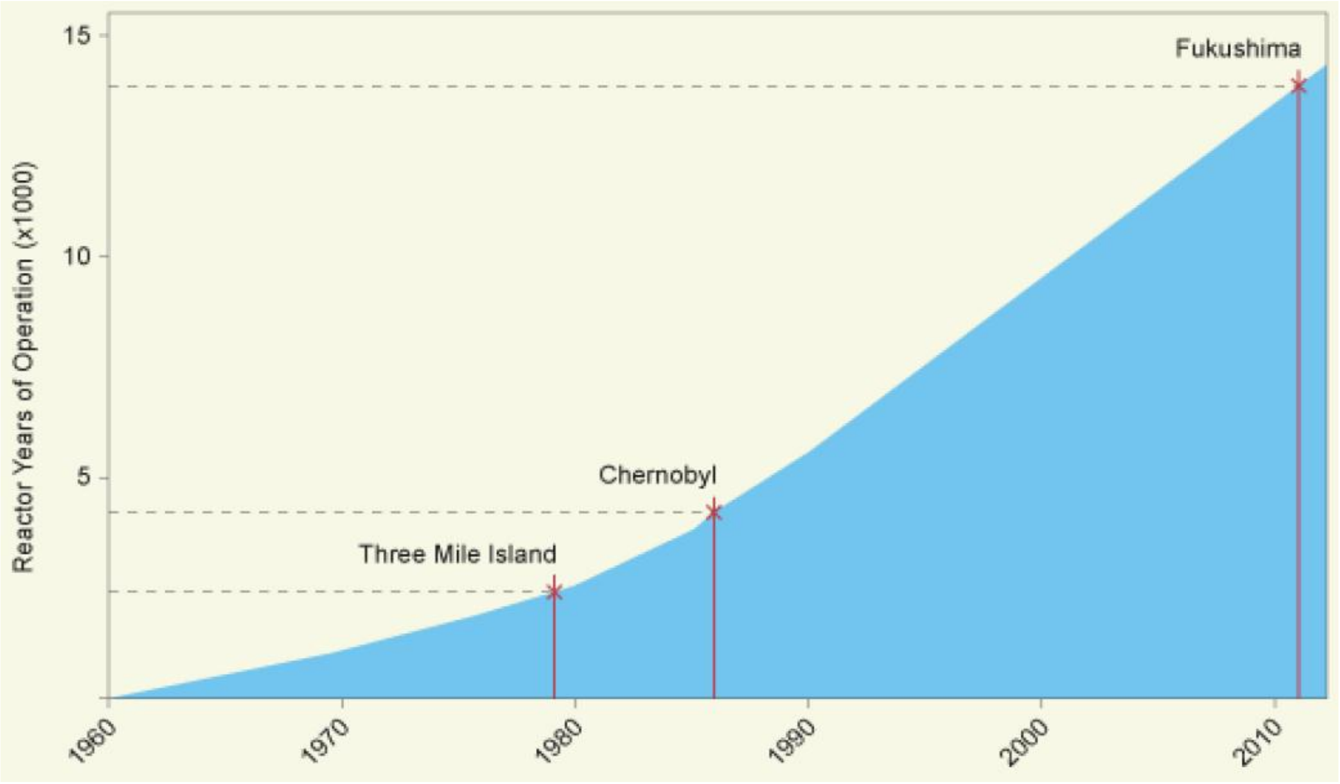
Uncertainty…



고수 VS. 하수

RBDM VS. RIDM

Severe Accident & PSA



[http://www.world-nuclear.org/info/inf06.html]

후쿠시마

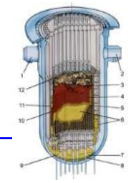
초기 사건

[기기 고장]

[인적 오류]

[자연 재해]

[인적 재해]



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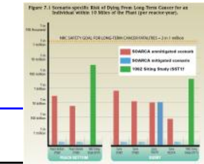
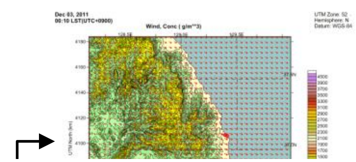
2단계 PSA: 격납건물 파손빈도 및 방사성 물질 누출량

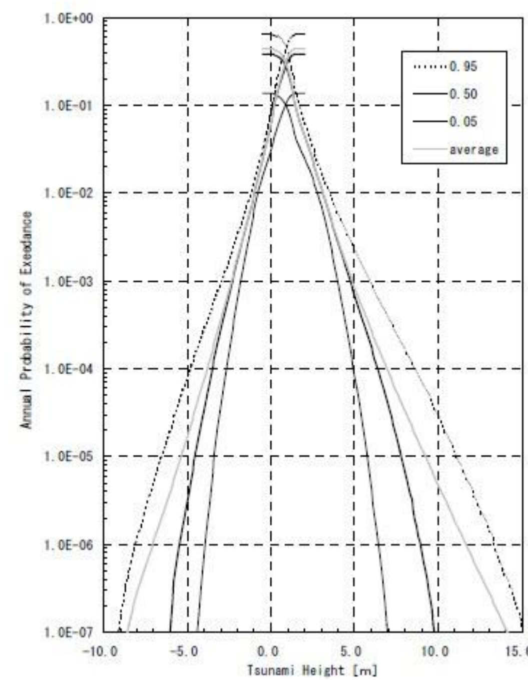
	중대 사고	격납 건물	결과
			OK
			(
			방 물질

- Leak/I
- STC 별



3단계 PSA: 방사성 물질 확산 및 피폭





(a) Long-term-: Near-field + Far-field

List of External Events

- Aircraft impact
- Avalanche
- Coastal erosion
- Drought
- External flooding
- Extreme winds and tornadoes
- Fire
- Fog
- Forest fire
- Frost
- Hail
- High tide, high lake level, or high river stage
- High summer temperature)
- Hurricane
- Ice cover
- Industrial or military facility accident
- Internal flooding
- Landslide
- Lightning
- Low lake or river water level
- Low winter temperature
- Meteorite
- Pipeline accident (gas, etc.)
- Intense precipitation
- Release of chemicals in onsite storage
- River diversion
- Sandstorm
- Seismic activity
- Snow
- Soil shrink-swell consolidation
- Storm surge
- Transportation accidents
- Tsunami
- Toxic gas
- Turbine-generated missile
- Volcano activity
- Waves
- Fuel handling machine drop

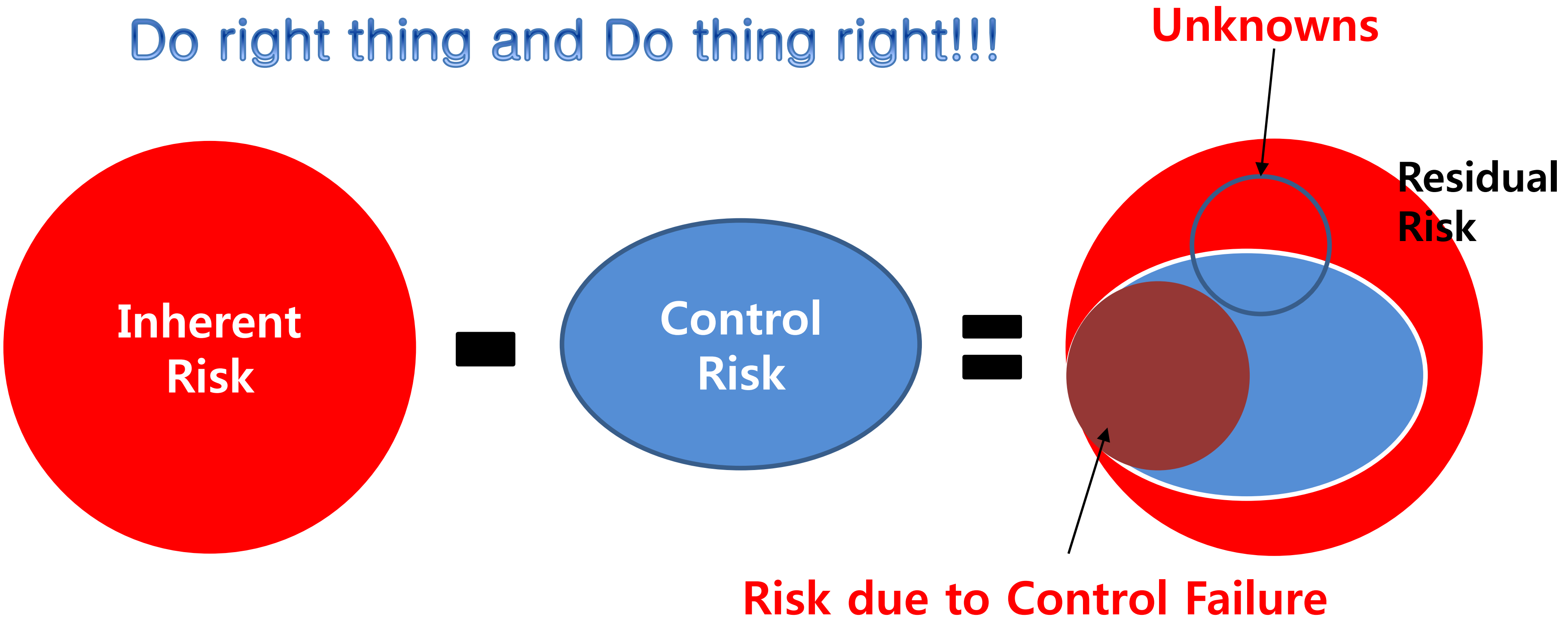
* Marine Lives

국민 수용성

- 850,000 will die if a severe accident occurs at Kori (by using the SEO code)
  - Economic Damage ~ 1 trillion USD

원전 안전성 확보 방안

Do right thing and Do thing right!!!

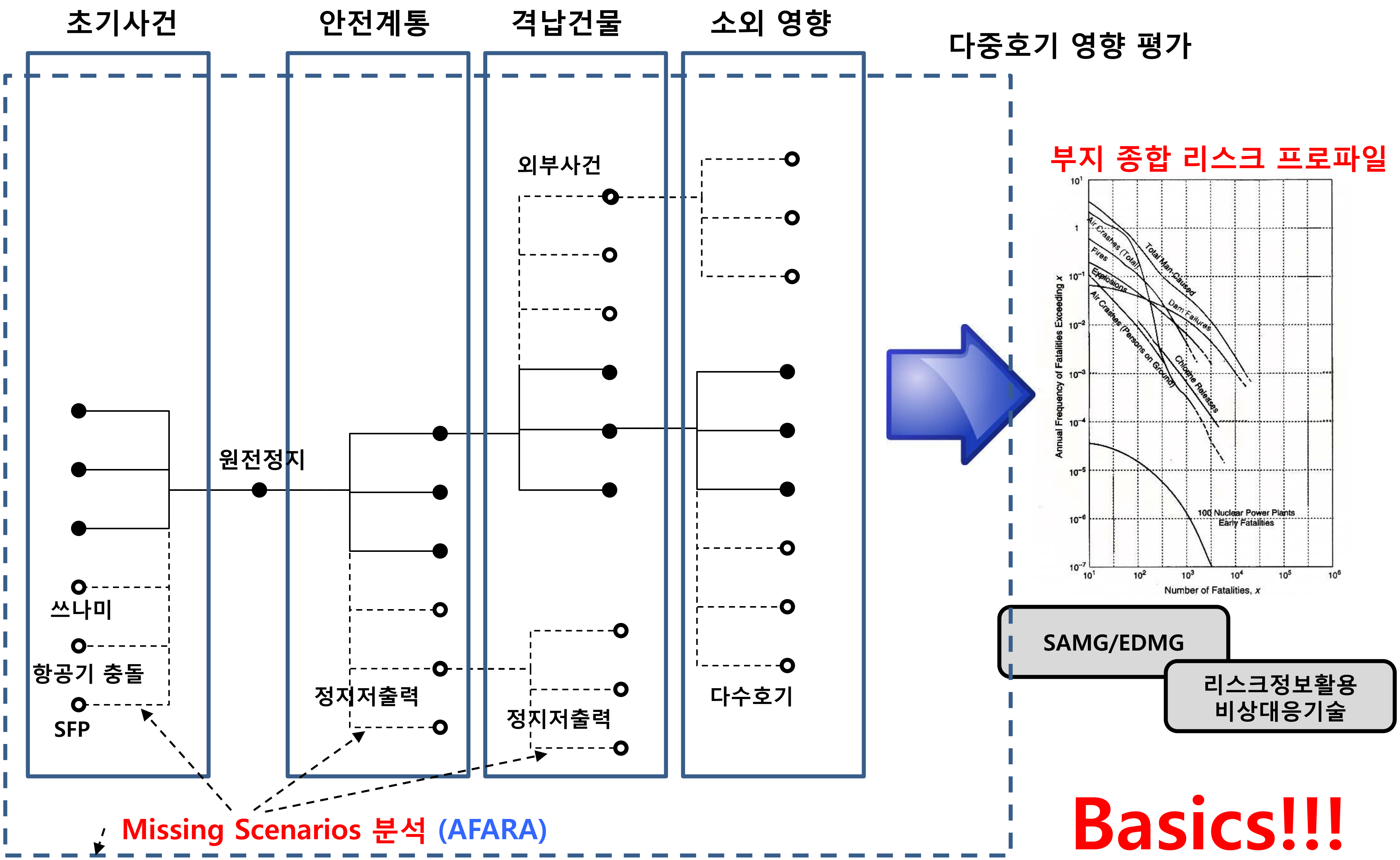


- 원전 안전성 향상 전략 (최종 목표: 방사능 물질의 외부 누출 방지)
  - Controlled Risk 영역의 확장→ 설계/설비 강화 (예방)
  - Failure of Control Risk 영역의 축소→ 운영 향상 (예방)
  - Residual Risk 에 대한 대비 강화→ 중대 사고 관리 전략 (완화)

Current Scope of PSA (after LPSD PSA)

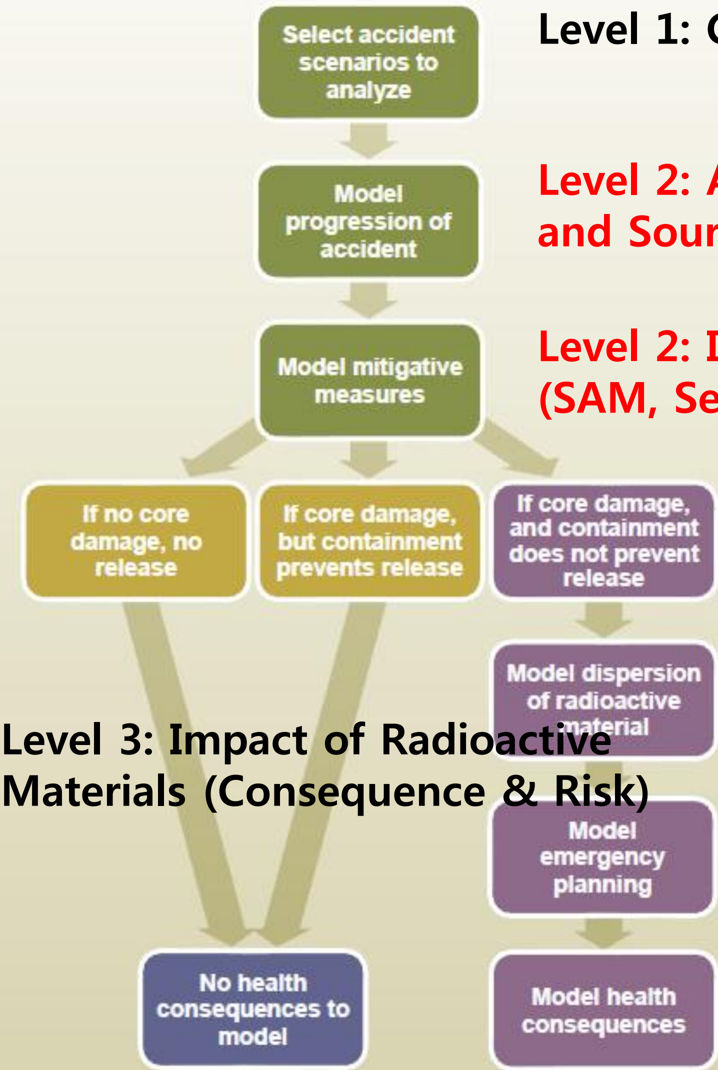
Model	Hazard	Level 1	Level 2	Level 3
Full Power	Internal	O	O	∆ (APR)
	Internal Fire	∆ (OPR)	O	X
	Internal Flooding	O	O	X
	Seismic	O	O	X
	Other External Events	X	X	X
LPSD	Internal	∆ (LPSD)	∆ (OPR/WS)	X
	Internal Fire	X	X	X
	Internal Flooding	∆ (LPSD)	X	X
	Seismic	∆ (LPSD)	X	X
	Other External Events	X	X	X

Missing Scenarios & Risk Profile



SOARCA (2013)

Figure 1.2 Flow Chart of the SOARCA Process.



Level 1: Core Damage Sequences (CDF)

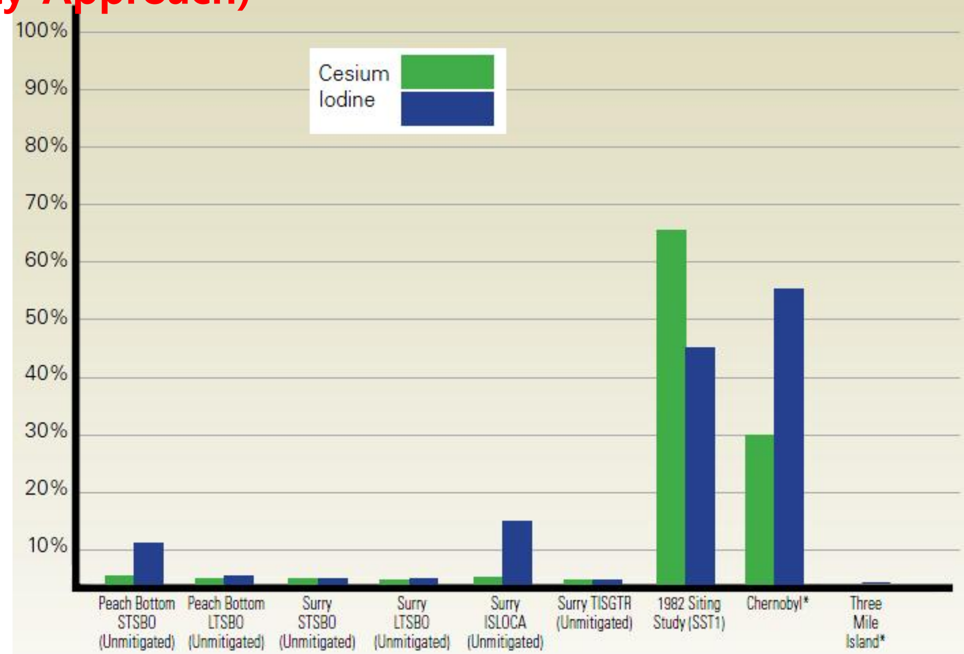
Level 2: Accident Progression (LRF) and Source Term Release

Level 2: Impact of Mitigation Measures (SAM, Sensitivity Approach)

Level 3: Impact of Radioactive Materials (Consequence & Risk)

Figure [illegible] Percentages of Iodine and Cesium Released to the Environment During the First 48 Hours of the Accident for SOARCA Unmitigated Scenarios, 1982 Siting Study (SST1), and Historical Accidents.

This figure compares how much iodine-131 and cesium-137 that are normally in the reactor core gets released in each accident scenario. The SOARCA unmitigated releases are much smaller than estimated in the earlier 1982 Siting Study Siting Source Term 1 (SST1) case. Also note that these releases can begin as early as 3.5 hours (for Surry STSBO with TISGTR) to as late as 45 hours (for Surry LTSBO), and some of these releases develop over a period of time. For comparison, releases from the Chernobyl and Three Mile Island accidents are included.

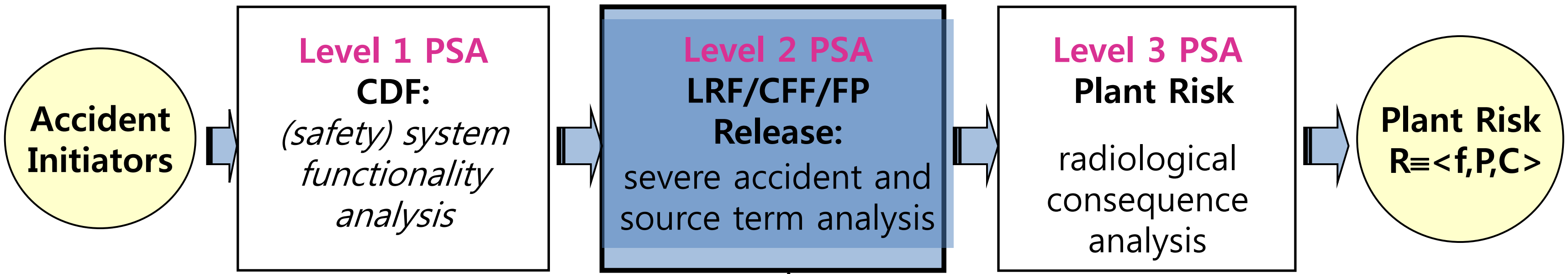


* Chernobyl release data is estimated at 20-40 percent for cesium-137 and 50-60 percent for iodine-131. Three Mile Island released an extremely small quantity of iodine-131 (~ 15 curies) and zero cesium-137.

PSA와 중대사고의 연결 부분

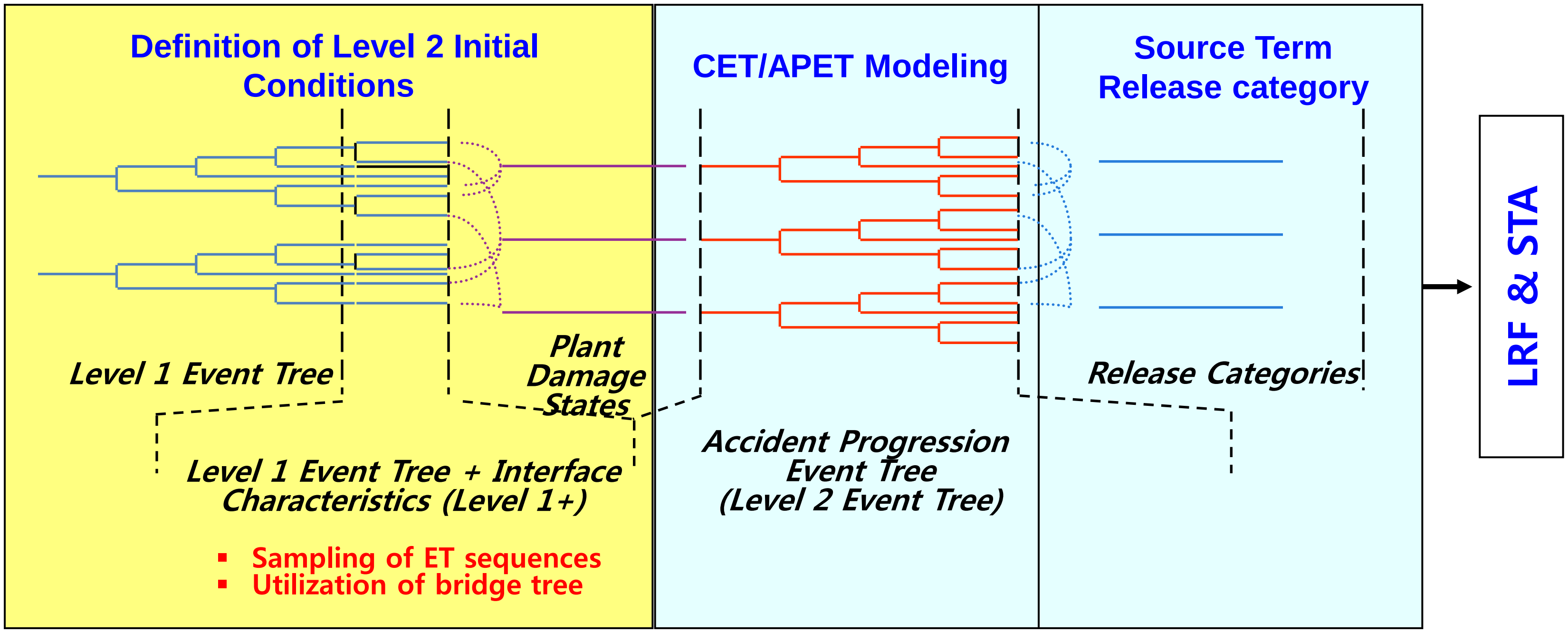
Level 2 PSA (1/2)

Level 2 PSA 분석대상 (1/2)



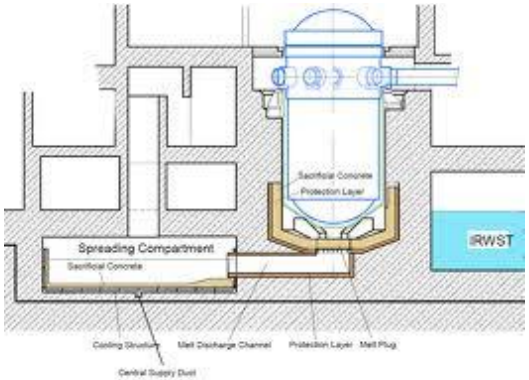
단계	주요 평가 대상	안전 변수	주요 결과	분석시간 (mission time)
Level 1	• 초기사건 분석 • 계통 성공/실패 여부 • 운전원 조치 여부	• 노심 반응도 제어 • 노심 냉각재 재고량 • 노심 열 제거 능력	• 계통 신뢰도 • 노심손상 빈도	사고발생 후 대략 24시간
Level 2	• 중대사고 물리적 현상 • 격납건물 안전계통 영향 • 선원항(Source Term) • 사고완화전략	• 격납건물 열/압력 부하 • 격납건물 기계적 부하	• 격납건물 파손 형태 및 확률 • 방사선원 방출 및 빈도	사고발생 후 대략 72시간 *LERF = VB 전후 또는 4시간 이내
Level 3	• 핵분열생성물 확산 • 방사능 피폭 경로 • Consequences	• 방사능 피폭효과 • FPs 대기확산	• 방사선량 • 조기 치사율 • 후기 치사율	격납건물 파손 후 수 일

Level 2 PSA (2/2)



연계 강화 방안 필요 분야...

- **PSA 관련 (Minimize the Failure of Control Risk)**
  - 국내 고유 중대사고 현상 발생 확률 평가
  - 국내 고유 Source Term 확인
  - Level 2 PSA에의 SAMG 반영
  - Level 3 PSA & SOARCA like study
    - 국내원전 Benchmark Analysis



- **중대 사고 관리 관련 (Minimize the Consequences of All Residual Risk)**
  - 사고진행에 따른 절차서 및 지침서(EOP/SAMG/EDMG) 개발/평가/개정
  - 중대사고 관리 지침서(SAMG/EDMG) 세부전략 개발/평가/개정
    - 유효성 검토
  - Risk-Informed AM(중대사고 시나리오 활용 방안)

중대사고와 PSA 협력 가능 분야 (1/3)

(1) 국내고유 중대사고 현안 및 발생확률 평가

(Risk-oriented approach / BEPU / Expert Opinion Elicitation Panel)

안전/성능 목표 및 관련 현안 파악

↓

관련 현안 분석 및 평가

↓

관련 현안 별 평가체제 반영 (규제요건/리스크)

↓

최적평가(BEPU) 및 안전목표와 비교

Hydrogen Mitigation & S/E
Core Debris Coolability
Containment Overpressurization
High Pressure Melt Ejection
Equipment Survivability

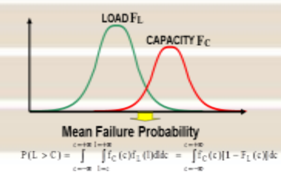
SA Phenomenological Issues

AM Strategy : IVR/ERVC, FCVS …

Test Programs
Computer Code Development
Analytical Methods

Integral codes, Dedicated codes

Regulatory Requirements
Risk Considerations
Unique Design Issues



Deterministic and/or BE Analyses

+ uncertainty

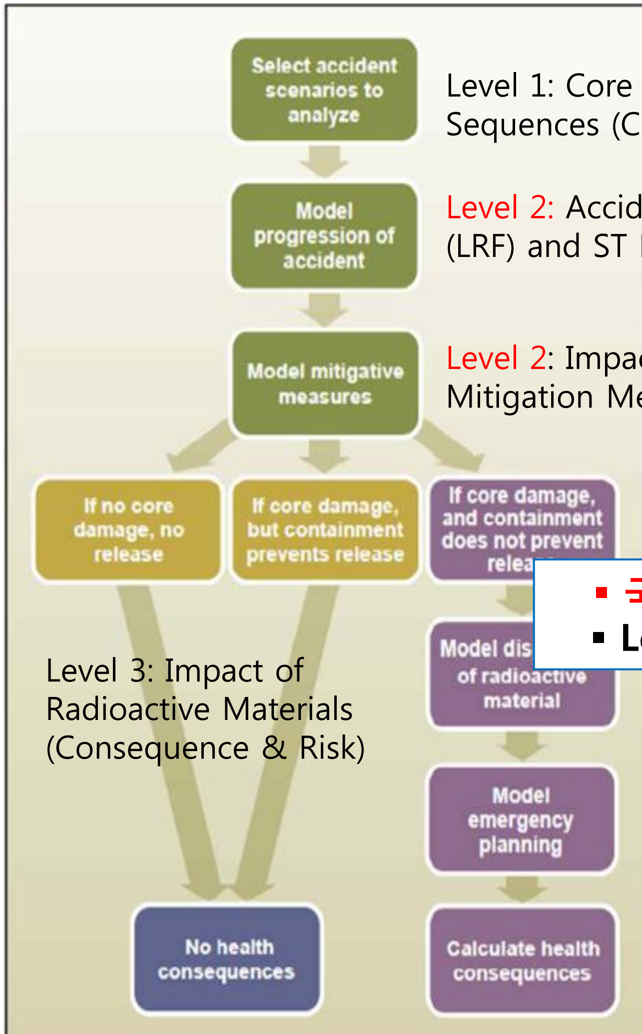
Probabilistic Risk Assessment

- Relevant experiments
- Other PSA studies
- State of art review
- Expert opinions

국내 고유 중대사고 현상 발생 확률 평가 DB

중대사고와 PSA 협력 가능 분야 (2/3)

(2) 국내고유 ST/Consequences 평가 : SOARCA Benchmark?



Level 1: Core Damage Sequences (CDF)

Level 2: Accident Progression (LRF) and ST Release

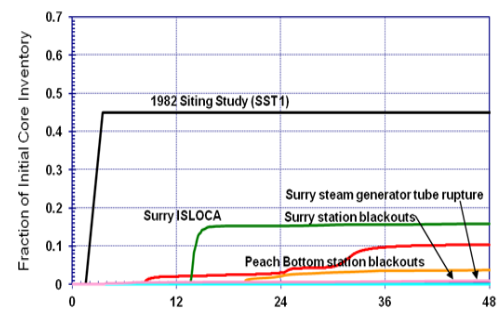
Level 2: Impact of Mitigation Measures (SAM)

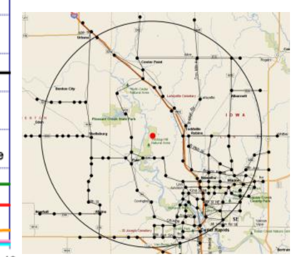
Level 3: Impact of Radioactive Materials (Consequence & Risk)

- **국내 PSA : MAAP**
- **Level 3 : MACCS2**

SOARCA (NUREG-1935, 2012)

- **분석대상 /사고경위** : Surry/Peach Bottom → STSBO/LTSBO/TI-SGTR/ISLOCA (**SPAR Model, Frequency/Consequence-based**)
- **MELCOR 코드를 이용한 중대사고 상세 분석**
- **사고완화조치(Mitigation) 등을 포함한 비상대응의 적절성 평가 (MACCS2)**

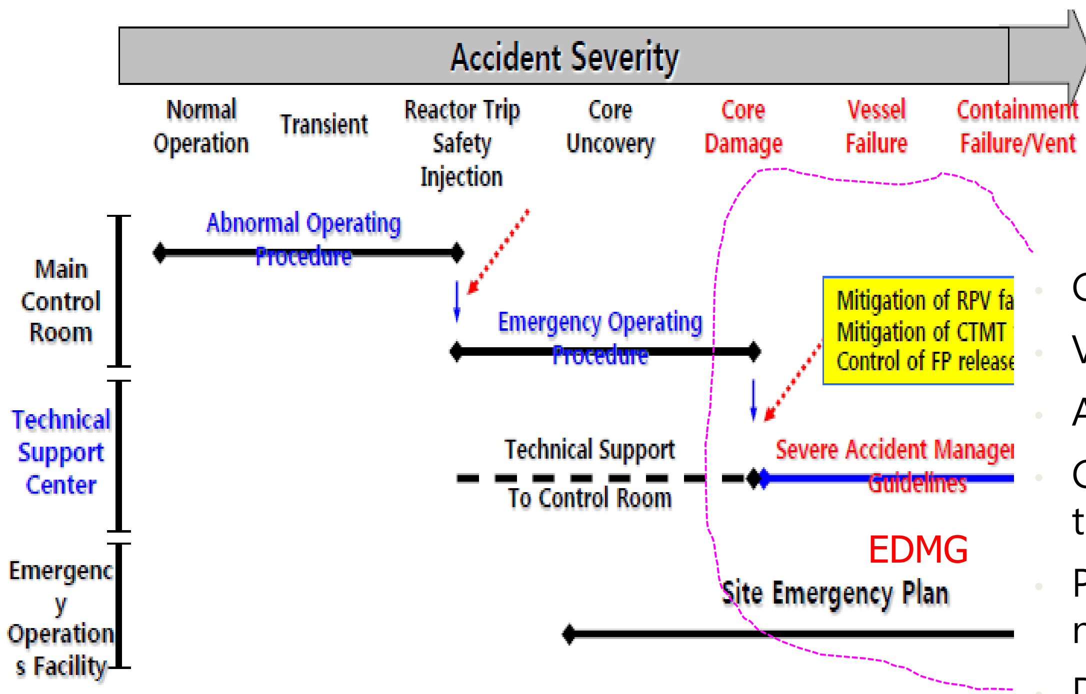




중대사고와 PSA 협력 가능 분야 (3/3)

(3) 국내 원전 사고관리 전략 평가 및 개선

(SAMG/EDMG Strategies / EOP-SAMG-EDMG Consistency)



Severe Accident Management Guidelines

Purpose
- Protect fission product boundaries
- Mitigate releases
- Mitigate severe accident phenomena
- Restore controlled stable condition

Features
- Implemented by TSC
- Separate from EOPs
- Symptom based

Code Simulation을 통한
SAMG/EDMG 시나리오 및 전략 평가:

- Gain insight into SAMG actions
- Verify the merit and advantages
- Ascertain the potential negative impacts
- Characterize the plant conditions with time while executing a mitigation action
- Provide feedback to SAMG refinement, if needed
- Document SAMG action simulations to support the technical assessment team to recommend mitigation actions

PSA 분야가 중대사고 분야에 원하는 것

PSA와 중대사고 분야 연계 강화 방안

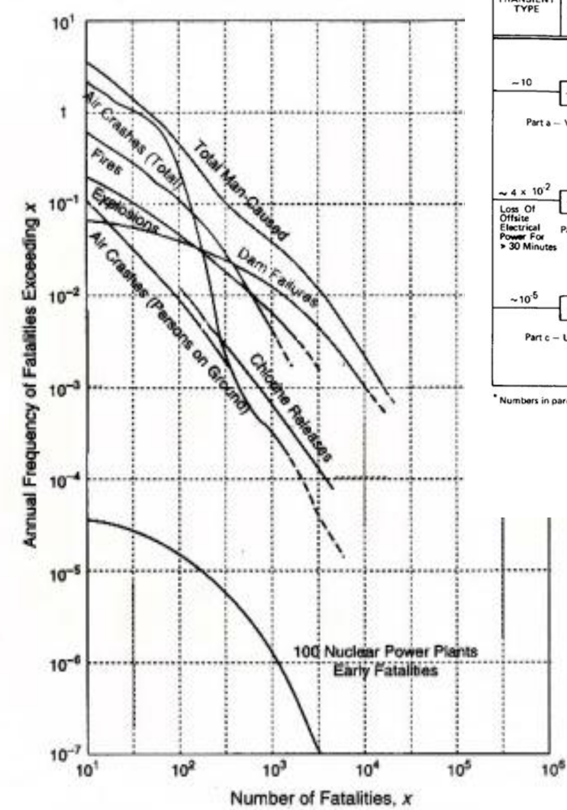
- **리스크/중대사고 분야 문제점**
  - 중대사고/PSA에 대한 명확한 규제 정책 부재
  - 확률론적(PSA) 관점과 결정론적(SA) 관점의 인식 차이
  - 관련분야(중대사고/Level 2&3 PSA) 전문인력 부족

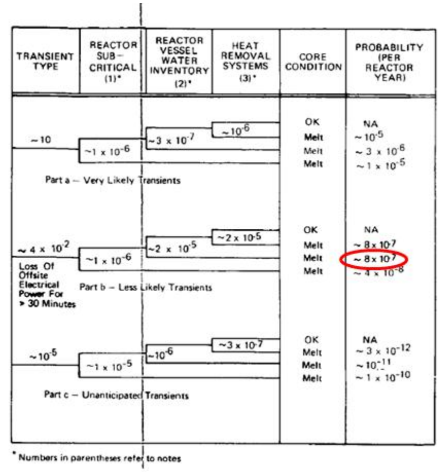
- **Fukushima 사고 후 환경 변화**
  - 중대사고 분야: Consequence 중심의 중대사고 대응전략 수립 강화
  - 리스크 분야: Residual Risk 보완을 위한 리스크 분석대상/범위 확대 추세 (FP, LPSD, SFP, Extreme External Hazards: LOLA/Site Risk 등)

- **제언**
  - PSA/중대사고 공통 관심사안 도출 (연구/활용분야 우선순위 선정)

  → **Harmonization & Cross-cutting!!!**

PSA in the U.S.A.





[WASH-1400, 1975]

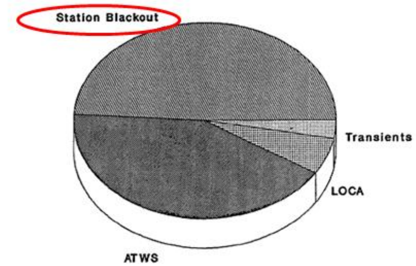
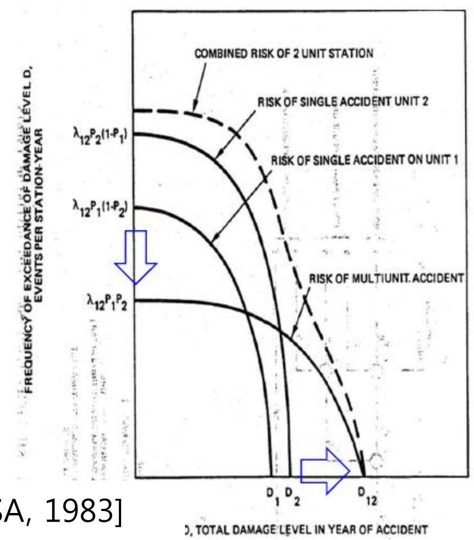


Figure 4.3 Contributors to mean core damage frequency from internal events at Peach Bottom.

[NUREG-1150, 1990]



[Seabrook PSA, 1983]

- 중대사고 현상에 대한 이해
- 불확실한 상황에서의 의사 결정

Into the real world!

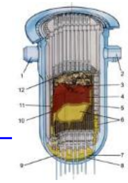
초기 사건

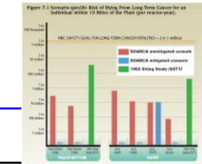
[기기 고장]

[인적 오류]

[자연 재해]

[인적 재해]





1단계 PSA: 노심손상빈도

	안전 계통 1	안전 계통 2	결과
빈도			OK
			OK
			노심 손상

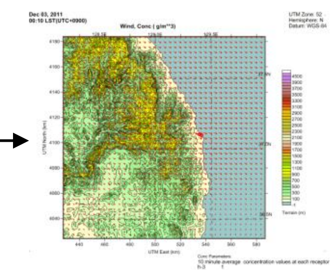
- 기기(펌프/밸브) 고장 (정비/보수)
- 인적 오류 (절차서)
- 공통원인 고장

2단계 PSA: 격납건물 파손빈도 및 방사성 물질 누출량

중대 사고	격납 건물	결과
		OK
		OK
		방사성 물질 누출

- Leak/Rupture
- STC 별 방출량

3단계 PSA: 방사성 물질 확산 및 피폭

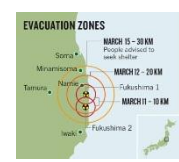


- Fatality
- 환경 오염

절차서 개선

설계/기기 개선

중대사고 전략 개선 (EOP-SAMG-EDMG)



비상 대응개선

면진 설비

물리적 방호 (핵심구역)

감사합니다

국가 미래 에너지를 책임지는 연구원

Any Questions??

KAERI 한국원자력연구원
Korea Atomic Energy Research Institute