بسم الله الرحمن الرحيم

انجمن حفاظت در برابر اشعه
کنفرانس دو سالانه – اسفند ۱۴۰۲

تحول در اصول بنیادی ایمنی نیروگاههای هسته ای

پس از حادثه فوکوشیما

رویکرد های جدید به طبقه بندی حوادث و دفاع درعمق

Post Fukushima Approaches to

Accidents Categorization and Defense in Depth Strategy

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روز آمد : ۱۴۰۲/۱۱/۲۵

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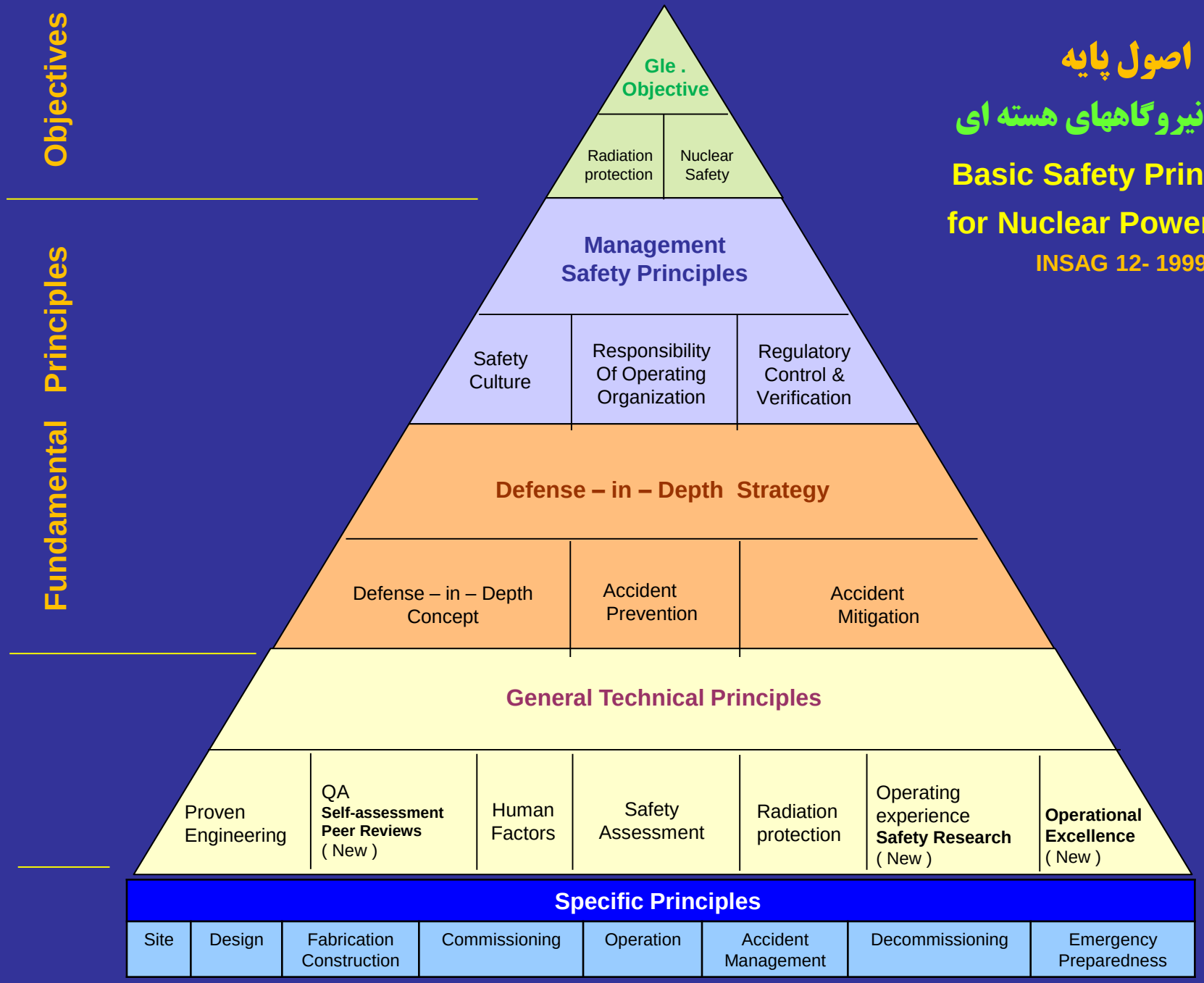
اصول پایه
ایمنی نیروگاههای هسته ای
Basic Safety Principles for Nuclear Power Plant

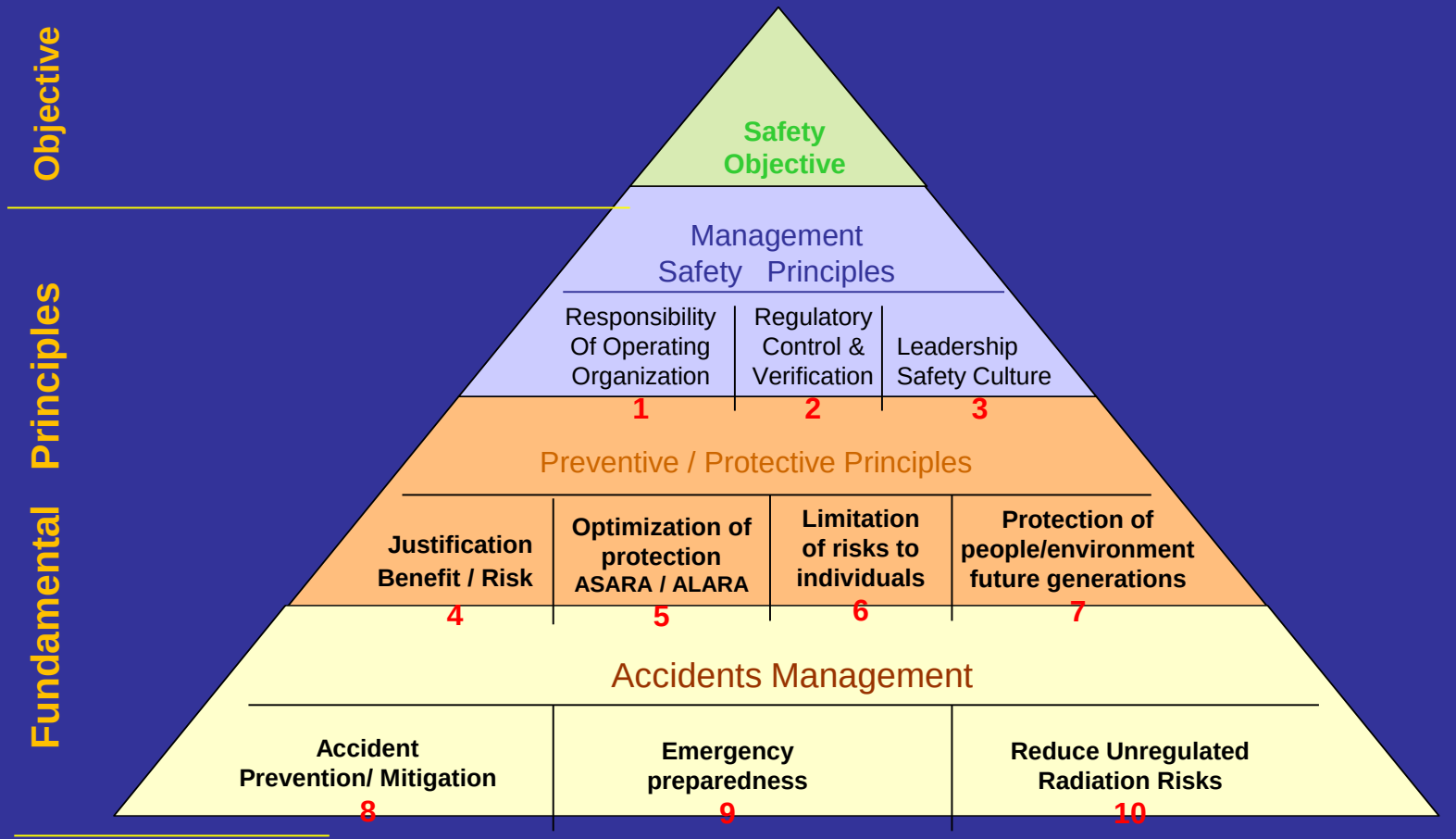
INSAG 12- 1999



اصول بنیادی ایمنی تاسیسات هسته ای

ده فرمان ایمنی هسته ای

(IAEA-SF-1, 2006)



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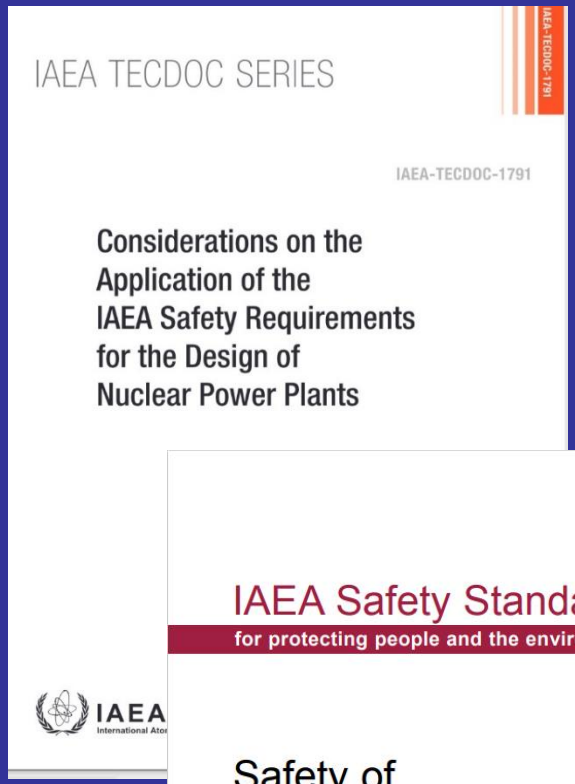

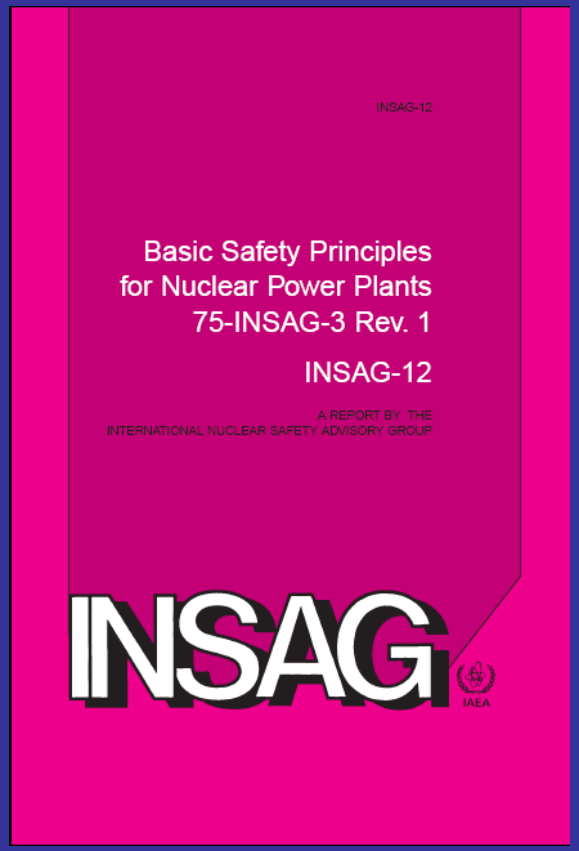

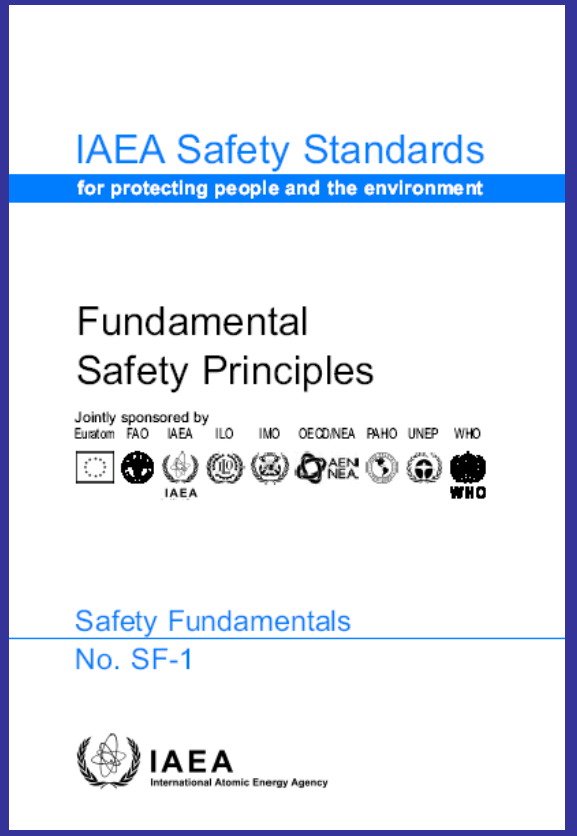

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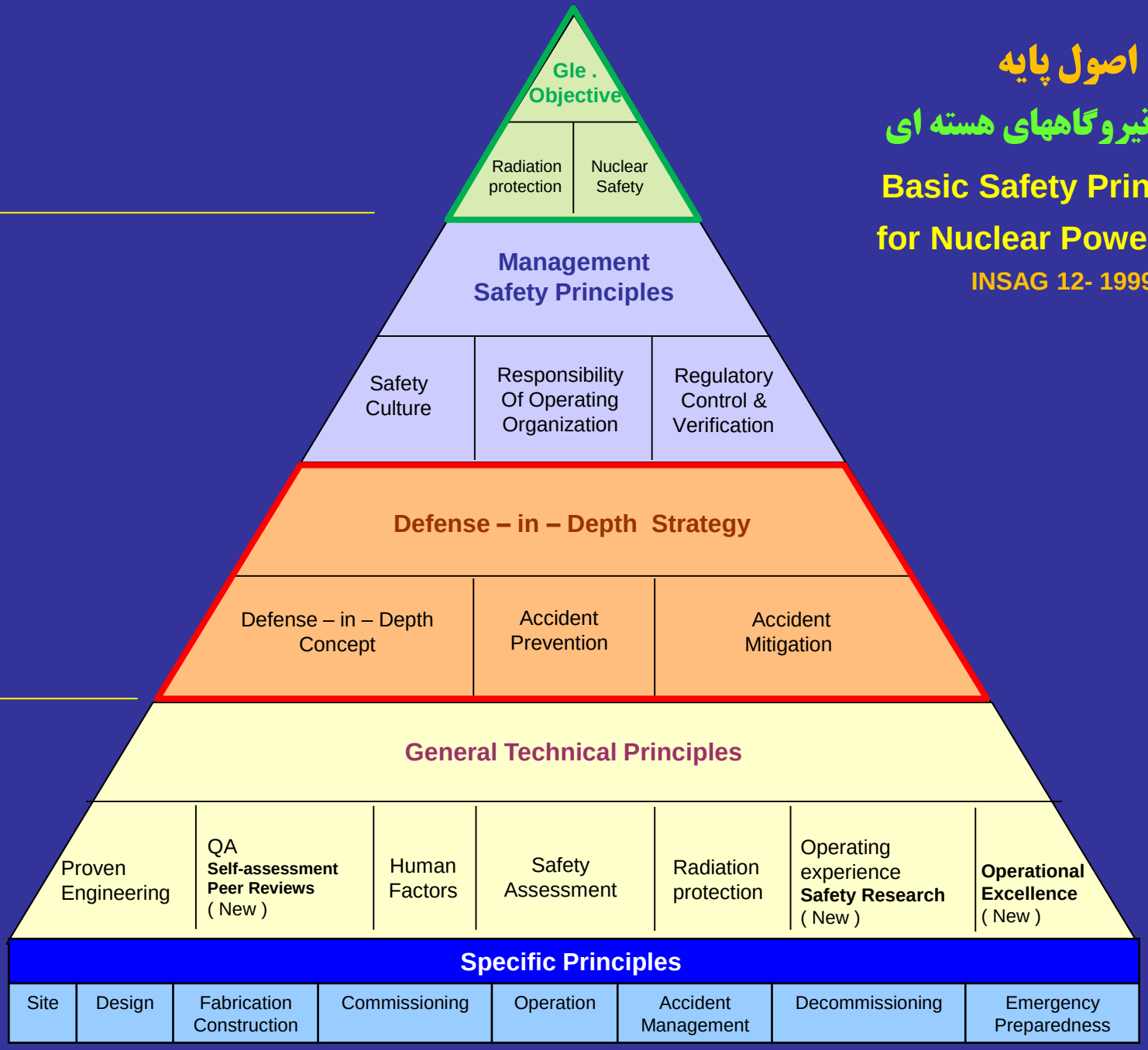
اصول پایه
ایمنی نیروگاههای هسته ای

Basic Safety Principles for Nuclear Power Plant

INSAG 12- 1999

Objectives

Fundamental Principles



اهداف ایمنی هسته ای

هدف کلی

حفاظت افراد ، جامعه ، و محیط زیست

دربرابر مخاطرات رادیولوژیک

از طریق برقراری و حفظ یک **دفاع** موثر در نیروگاه

2.1 GENERAL NUCLEAR SAFETY OBJECTIVE

13. Objective: *To **protect** individuals, society and the environment , **by** establishing and maintaining , in nuclear power plants , an **effective defence**, **against** radiological hazard.*

Table 2-1. Nuclides, half-life and radioactivity for a 1000 MWe PWR

		Nuclide	Half-life (days)	Radioactivity ($Bq \times 10^{18}$)	Radioactivity (MCi)
Noble Gases	Krypton	^{85}Kr	3950	2.072	56
		^{85m}Kr	0.183	0.888	24
		^{87}Kr	0.0528	1.739	47
		^{88}Kr	0.117	2.516	68
	Xenon	^{133}Xe	5.28	6.290	170
		^{135}Xe	0.384	1.258	34
Iodine	Iodine	^{131}I	8.05	3.145	85
		^{132}I	0.0958	4.440	120
		^{133}I	0.875	6.290	170
		^{134}I	0.0366	7.030	190
		^{135}I	0.28	5.550	150
Caesium & Rubidium	Caesium	^{134}Cs	750	0.2775	7.5
		^{136}Cs	13	0.111	3
		^{137}Cs	11 000	0.1739	4.7
	Rubidium	^{86}Rb	18.7	0.00096	0.026
Tellurium & Antimony	Tellurium	^{127}Te	0.391	0.2183	5.9
		^{127m}Te	109	0.0407	1.1
		^{129}Te	0.048	1.147	31
		^{129m}Te	0.34	0.1961	5.3
		^{131m}Te	1.25	0.481	13
		^{132}Te	3.25	4.44	120
	Antimony	^{127}Sb	3.88	0.2257	6.1
		^{129}Sb	0.179	1.221	33
Alkaline Earths	Strontium	^{89}Sr	52.1	3.478	94
		^{90}Sr	11 030	0.1369	3.7
		^{91}Sr	0.403	4.07	110
	Barium	^{140}Ba	12.8	5.92	160
Volatile Oxides	Cobalt	^{58}Co	71	0.02886	0.78
		^{60}Co	1920	0.01073	0.29
	Molybdenum	^{99}Mo	2.8	5.92	160
	Technetium	^{99m}Tc	0.25	5.18	140
	Ruthenium	^{103}Ru	39.5	4.07	110
		^{105}Ru	0.185	2.664	72
		^{106}Ru	366	0.925	25
		^{105}Ru	1.5	1.813	49
Non-volatile Oxides	Yttrium	^{90}Y	2.67	0.1443	3.9
		^{91}Y	59	4.44	120
	Zirconium	^{95}Zr	65.2	5.55	150
		^{97}Zr	0.71	5.55	150
	Niobium	^{95}Nb	35	5.55	150
	Lanthanum	^{140}La	1.67	5.92	160
	Cerium	^{141}Ce	32.3	5.55	150
		^{143}Ce	1.38	4.81	130
		^{144}Ce	284	3.145	85
	Praseodymium	^{143}Pr	13.7	4.81	130
	Neodymium	^{147}Nd	11.1	2.22	60
	Neptunium	^{239}Np	2.35	60.68	1640
	Plutonium	^{238}Pu	32 500	0.002109	0.057
		^{239}Pu	8.9×10^6	0.000777	0.021
		^{240}Pu	2.4×10^6	0.000777	0.021
		^{241}Pu	5350	0.1258	3.4
	Americium	^{241}Am	1.5×10^5	0.0000629	0.0017
				Total activity (EBq)	Total activity (MCi)
				193	5202

منشاء مخاطرات رادیولوژیک

نیروگاههای هسته ای

اهداف ایمنی هسته ای

هدف حفاظت در برابر پرتوها

(INSAG - 12)

حصول اطمینان از :

در بهره برداری عادی

پرتوگیری ، در داخل نیروگاه و ناشی از هر نوع رها سازی مواد رادیو اکتیو از نیروگاه ،
حد اقل موجه شدنی (رویکرد ALAR ، با توجه به عوامل اقتصادی واجتماعی) است

و زیرحدود تجویز شده (Prescribed Limits)

و در شرایط حادثه

مهار گسترش پرتوگیری ناشی از حوادث

توجه : اهداف حفاظت در برابر پرتوها از جنس پرتو پزشکی است

اهداف ایمنی هسته ای

هدف حفاظت در برابر پرتوها

(INSAG - 12)

2.2. RADIATION PROTECTION OBJECTIVE

16. **Objective:** ***To ensure*** ***in normal operation*** ***that radiation exposure, within the plant and due to any release of radioactive material from the plant, is as low as reasonably achievable, economic and social factors being taken into account, and below prescribed limits, and to ensure mitigation of the extent of radiation exposure*** **due to accidents.** **(IAEA - INSAG-12)**

اهداف ایمنی هسته ای

(INSAG - 12)

هدف فنی ایمنی

1. پیشگیری ، با اطمینان زیاد ، از : بروز حوادث در نیروگاه هسته ای

2. حصول اطمینان از : ناچیز بودن پیآمد های رادیولوژیک
با در نظر گرفتن تمامی حوادث ، حتی حوادث با احتمال بسیار کم ،
در طرح نیروگاه

3. حصول اطمینان از : بسیار کم (نادر) بودن احتمال وقوع حوادث وخیم
با پیامد های رادیولوژیک جدی

توجه : اهداف فنی ایمنی هسته ای از جنس مهندسی است

اهداف ایمنی هسته ای

هدف فنی ایمنی هسته ای

(INSAG - 12)

2.3. TECHNICAL SAFETY OBJECTIVE

19. Objective : ***To prevent with high confidence, accidents in nuclear plants; to ensure that, for all accidents taken into account in the design of the plant, even those of very low probability, radiological consequences, if any, would be minor; and to ensure that the likelihood of severe accidents with serious radiological consequences is extremely small ,*** **(IAEA - INSAG-12)**

فهرست مطالب

راهبرد دفاع درعمق ، رویکرد قبل از فوکوشیما

مفهوم دفاع عمقی (Defense-in-Depth Concept)

1. اعمال اصل دفاع عمقی : برای جبران خرابیهای بالقوه مکانیکی و انسانی
2. از طریق : برقراری یکسری لایه های دفاعی ، شامل حصار های ایمنی فیزیکی
3. برای اجتناب از رها سازی مواد رادیو اکتیو به محیط
4. شامل : حفاظت از خود حصار های ایمنی
5. پیش بینی : تمهیدات لازم برای حفاظت مردم و محیط در برابر مخاطرات ، در صورت موثر واقع نشدن حصارهای ایمنی

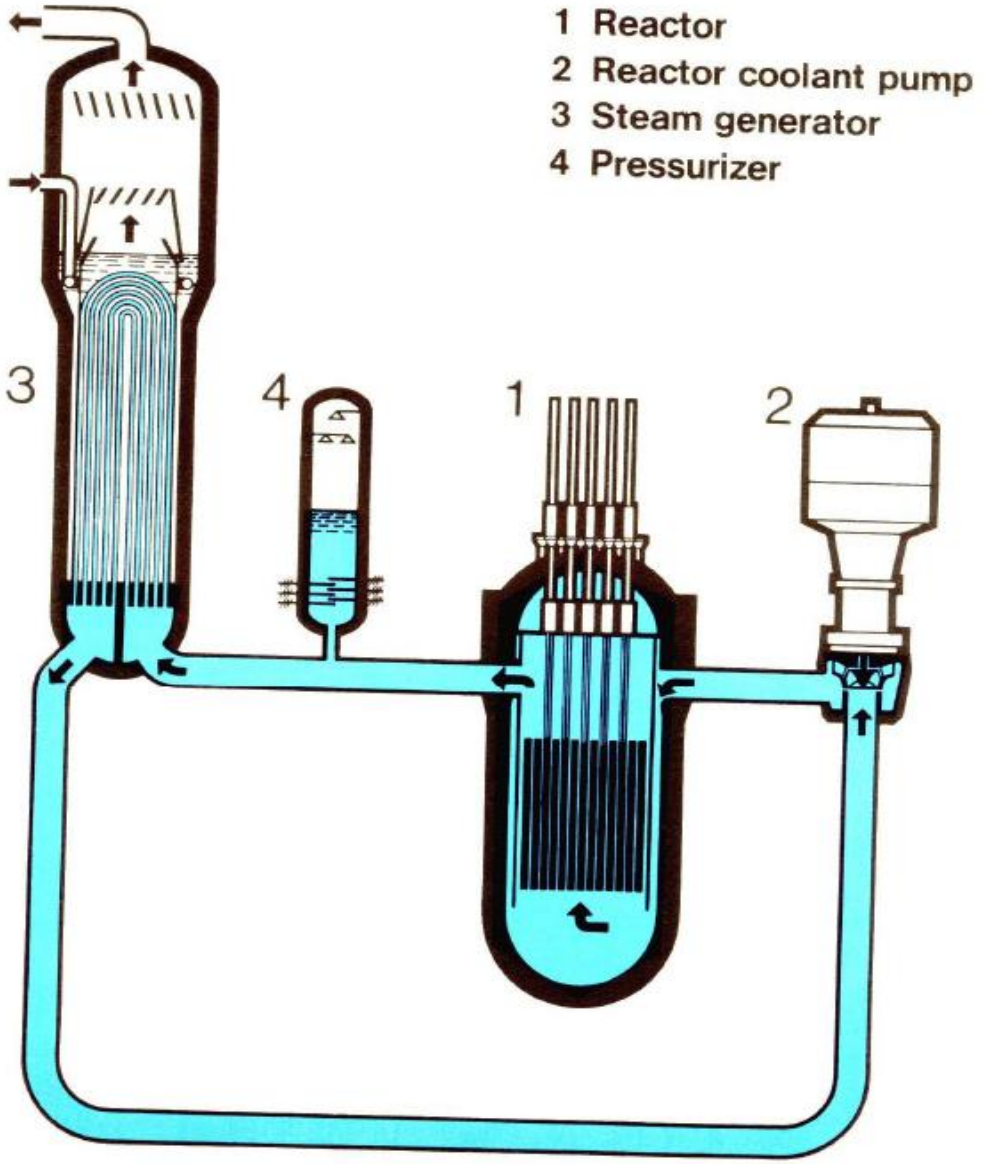
راهبرد دفاع درعمق ، رویکرد قبل از فوکوشیما

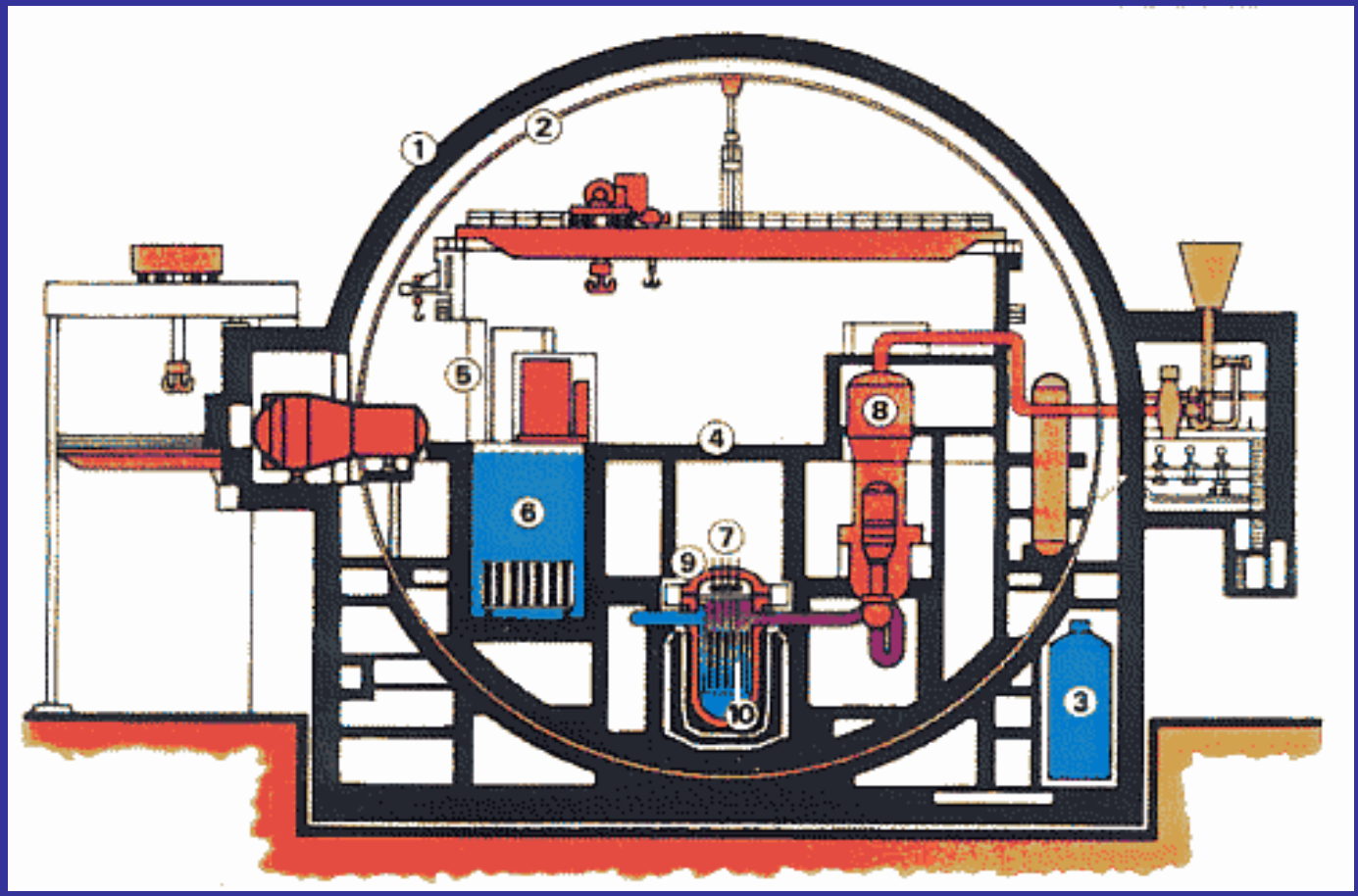
مفهوم دفاع عمقی (Defense-in-Depth Concept)

3.2.1 Defence in depth

46. Principle: To compensate, for potential human and mechanical failures, a defense in depth concept is implemented, centered on several levels of protection including successive barriers, preventing the release of radioactive material to the environment. The concept includes protection of the barriers by averting damage to the plant and to the barriers themselves. It includes further measures to protect the public and the environment from harm in case these barriers are not fully effective. (IAEA - INSAG-12)

راکتورهای
با آب سبک تحت فشار
PWR
مدار اول خنک کننده
دومین حصار ایمنی فیزیکی





راکتورهای
با آب سبک تحت فشار
PWR

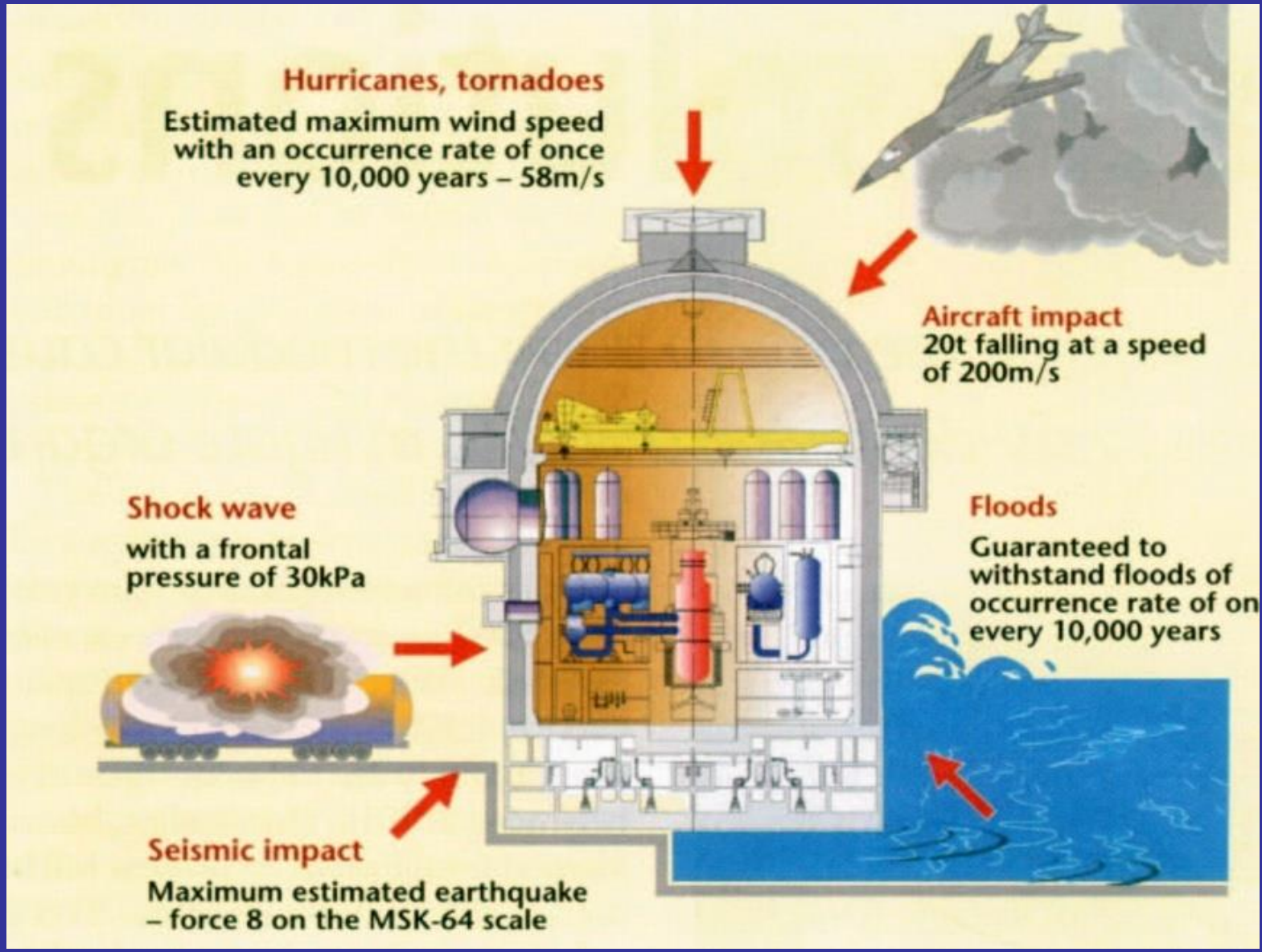
محفظه ایمنی راکتور

سومین حصار ایمنی فیزیکی

1) containment: pre-stressed concrete (2 m thick)
2) secondary containment: steel
3) accumulator tank
4) concrete shield
5) protection against missiles
6) water-cooled fuel pool
7) control rod drives
8) steam generator
9) reactor pressure vessel
10) reactor core : consists of a large number of fuel elements composed of fuel rods

Implementation of D in D in AES2006

AES-2006 ability to withstand external impacts



راهبرد دفاع درعمق ، رویکرد قبل از فوکوشیما

طبقه بندی رویداد ها و حوادث در نیروگاههای هسته ای

Plant States

Operational State		Accident Conditions		
Normal Operation	**Anticipated Operational Occurrence**	**Design Bases Accident**	**Beyond Design Bases Accident (BDBA)**	
NO	**AOO**	**DBA**	**Without significant Core Damage**	**Severe Accident**
	10E-2	10E-6	Rare	

Degree of Severity

Frequency [Ev/y]

راهبرد دفاع درعمق ، رویکرد قبل از فوکوشیما

طبقه بندی رویداد ها و حوادث در نیروگاههای هسته ای

Plant States

Operational State		Accident Conditions	
○ راه اندازی ○ توقف ○ سوخت گیری ○ نگهداری و تعمیرات ○ بار پذیری ○	○ رویداد های راکتیویته ○ قطع برق شبکه ○ کاهش / قطع جریان خنک کننده ○ افزایش / کاهش برداشت حرارت از مدار ثانویه ○	○ از دست رفتن آب خنک کننده ○ پرتاب میله کنترل ○ نشط از مدار اول به دوم ○ شکست لوله بخار ○	○ گذره های بدون توقف راکتور ○ ترکیب حوادث ○ خاموشی کامل نیروگاه ○ قطع کامل آب تغذیه مولد بخار ○ شکست مدار اولیه بدون تبرید اضطراری ○ حوادث خارجی ○ ....
Normal Operation	**Anticipated Operational Occurrence**	**Design Bases Accident**	**Beyond Design Bases Accident (BDBA)**
NO	**AOO**	**DBA**	**Without significant Core Damage** / **Severe Accident**
	10E-2	10E-6	Rare

Degree of Severity

Frequency [Ev/y]

راهبرد دفاع درعمق ، رویکرد قبل از فوکوشیما

مفهوم دفاع عمقی (D-i-D Concept)

TABLE I. LEVELS OF DEFENCE IN DEPTH IN EXISTING PLANTS

Levels	Objective	Essential means
Level 1	Prevention of abnormal operation and failures	Conservative design and high quality in construction and operation
Level 2	Control of abnormal operation and detection of failures	Control, limiting and protection systems and other surveillance features
Level 3	Control of accidents within the design basis	Engineered safety features and accident procedures
Level 4	Control of severe plant conditions, including prevention of accident progression and mitigation of the consequences of severe accidents	Complementary measures and accident management
Level 5	Mitigation of radiological consequences of significant releases of radioactive materials	Off-site emergency response

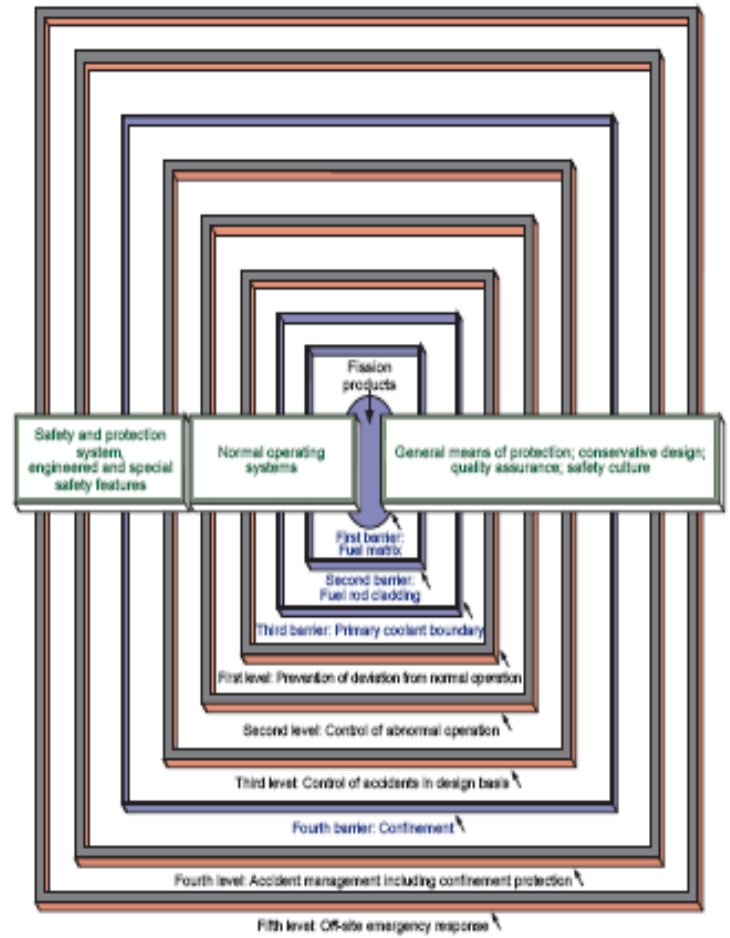
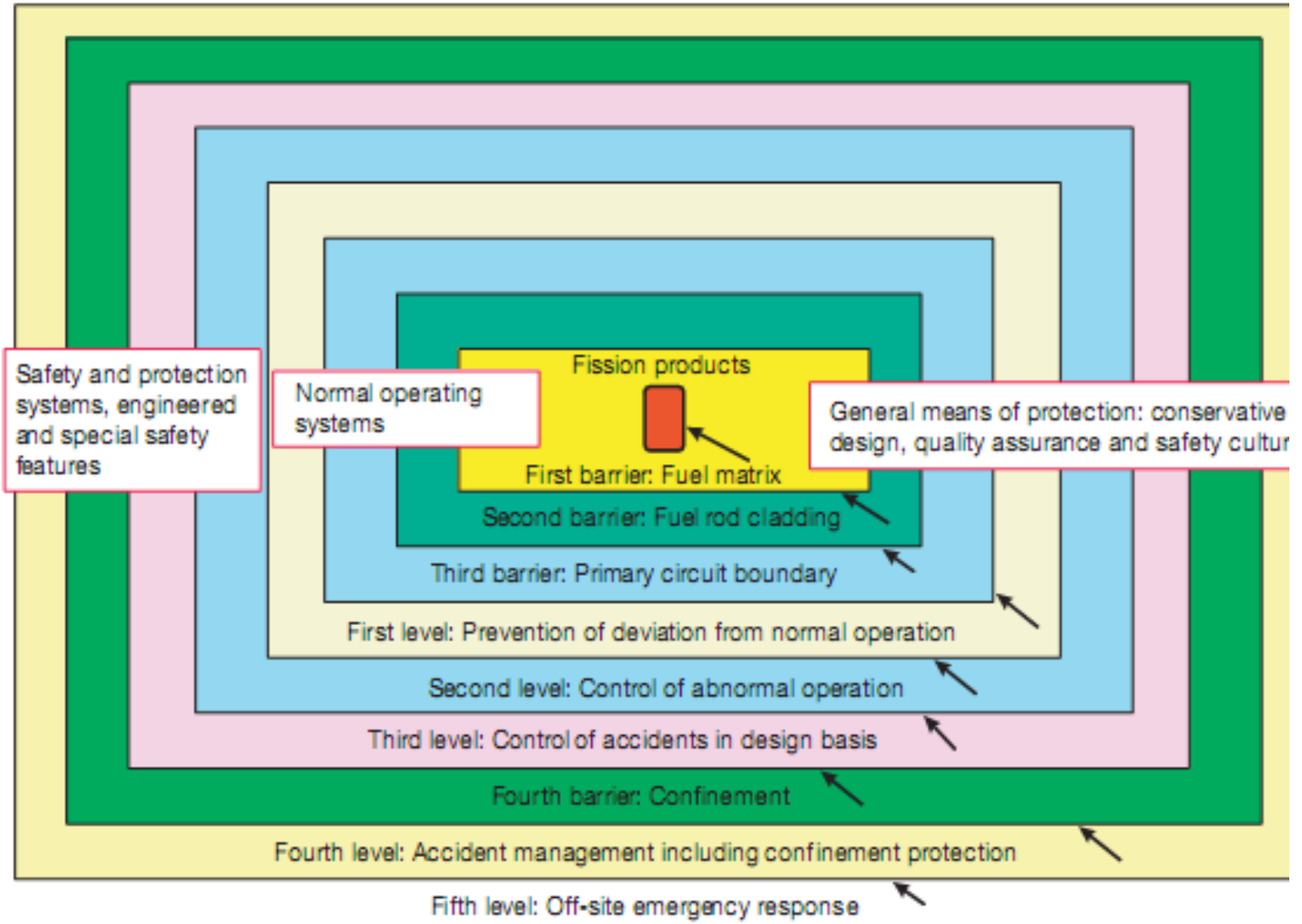


FIG. 4. The relation between physical barriers and levels of protection in defence in depth.

راهبرد دفاع درعمق ، رویکرد قبل از فوکوشیما

مفهوم دفاع عمقی (D-i-D Concept)



راهبرد دفاع درعمق ، رویکرد قبل از فوکوشیما

مفهوم دفاع عمقی (D-i-D Concept)

Strategy	Accident prevention			Accident mitigation	
Operational state of the plant	Normal operation	Anticipated operational occurrences	Design basis and complex operating states	Severe accidents beyond the design basis	Post-severe accident situation
Level of defence in depth	Level 1	Level 2	Level 3	Level 4	Level 5
Objective	Prevention of abnormal operation and failure	Control of abnormal operation and detection of failures	Control of accidents below the severity level postulated in the design basis	Control of severe plant conditions, including prevention of accident progression, and mitigation of the consequences of severe accidents, including confinement protection	Mitigation of radiological consequences of significant releases of radioactive materials
Essential features	Conservative design and quality in construction and operation	Control, limiting and protection systems and other surveillance features	Engineered safety features and accident procedures	Complementary measures and accident management, including confinement prodection	Off-site emergency response
Control	Normal operating activities		Control of accidents in design basis	Accident management	
Procedures	Normal operating procedures		Emergency operating procedures	Ultimate part of emergency operating procedures	
Response	Normal operating systems		Engineered safety features	Special design features	Off-site emergency preparations
Condition of barriers	Area of specified acceptable fuel design limit		Fuel failure; Severe fuel damage; Fuel melt	Uncontrolled fuel melt	Loss of confinement
Colour code	NORMAL		POSTULATED ACCIDENTS		EMERGENCY

FIG. 3. Overview of defence in depth.

راهبرد دفاع درعمق ، رویکرد قبل از فوکوشیما

اصول دفاع در عمق (D-i-D Principles)

1. **اصل پیشگیری از حوادث (Accident Prevention)**

- **تاکید روی پیشگیری از حوادث (بویژه حوادث منجر به صدمه جدی به قلب)**

به عنوان اولین اقدام دستیابی به ایمنی

2. **اصل مهار حوادث (Accident Mitigation) :**

- **در دسترس بودن امکانات مهارکننده (در داخل نیروگاه و خارج از سایت)**

برای کاهش قابل ملاحظه آثار رها سازی مواد رادیو اکتیو در اثر حوادث

راهبرد دفاع درعمق ، رویکرد قبل از فوکوشیما

اصول دفاع در عمق (D-i-D Principles)

3.2.2. Accident prevention

56. Principle: Principal emphasis is placed on the primary means of achieving safety, which is the prevention of accidents, particularly any which could cause severe core damage. (IAEA - INSAG-12)

3.2.3. Accident mitigation

63. Principle: In-plant and off-site mitigation measures are available and are prepared for that would substantially reduce the effects of an accidental release of radioactive material. (IAEA - INSAG-12)

رویکرد های پسا فوکوشیما به مفهوم دفاع در عمق

اصول پیشگیری و مهار حوادث قبل از فوکوشیما

NO

AOO

DBA

BDBA

SA

Accident Prevention

Accident Mitigation

TABLE I. LEVELS OF DEFENCE IN DEPTH IN EXISTING PLANTS

Levels	Objective	Essential means
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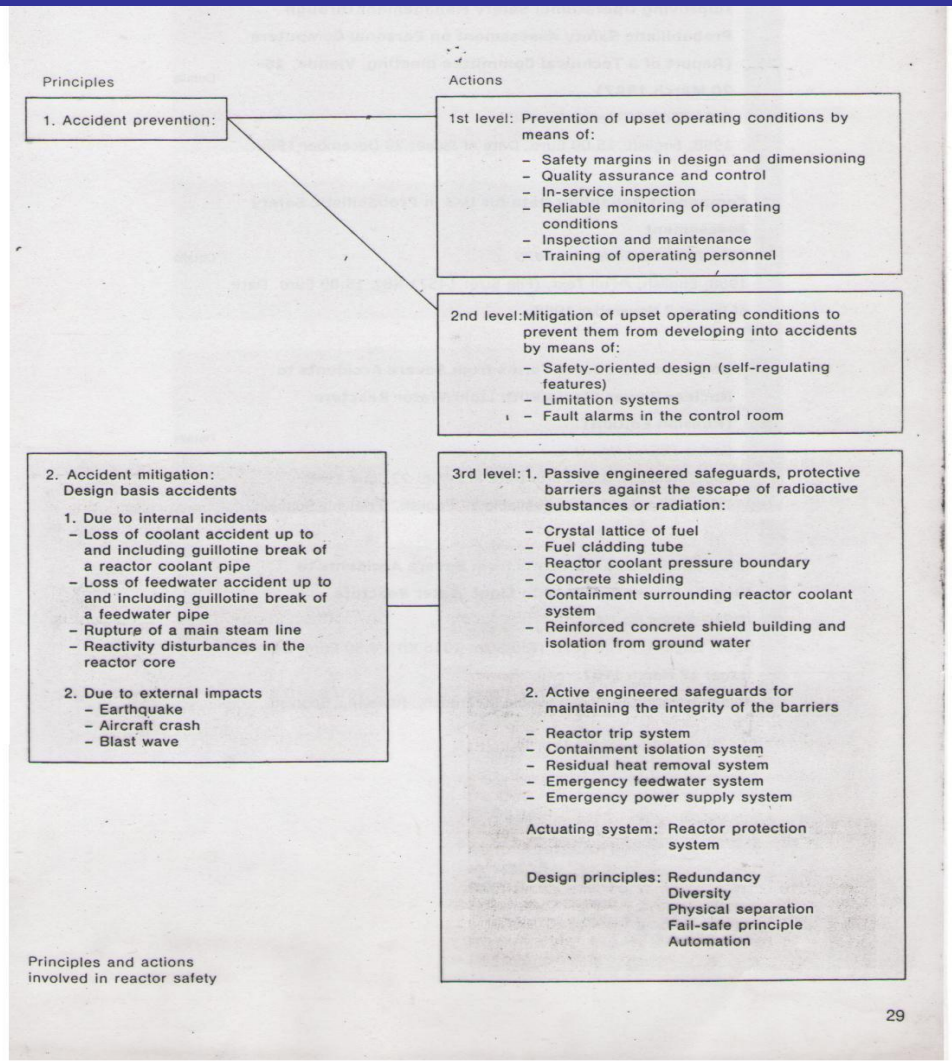
Level 5	Mitigation of radiological consequences of significant releases of radioactive materials	Off-site emergency response

راهبرد دفاع درعمق ، رویکرد قبل از فوکوشیما

تحول سطوح دفاع در عمق قبل و بعد از حادثه چرنوبیل

قبل از چرنوبیل



Principles and actions involved in reactor safety

29

بعد از چرنوبیل

TABLE I. LEVELS OF DEFENCE IN DEPTH IN EXISTING PLANTS

Levels	Objective	Essential means
Level 1	Prevention of abnormal operation and failures	Conservative design and high quality in construction and operation
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ممنون از توجه شما

فهرست مطالب

اصول پایه
ایمنی نیروگاههای هسته ای

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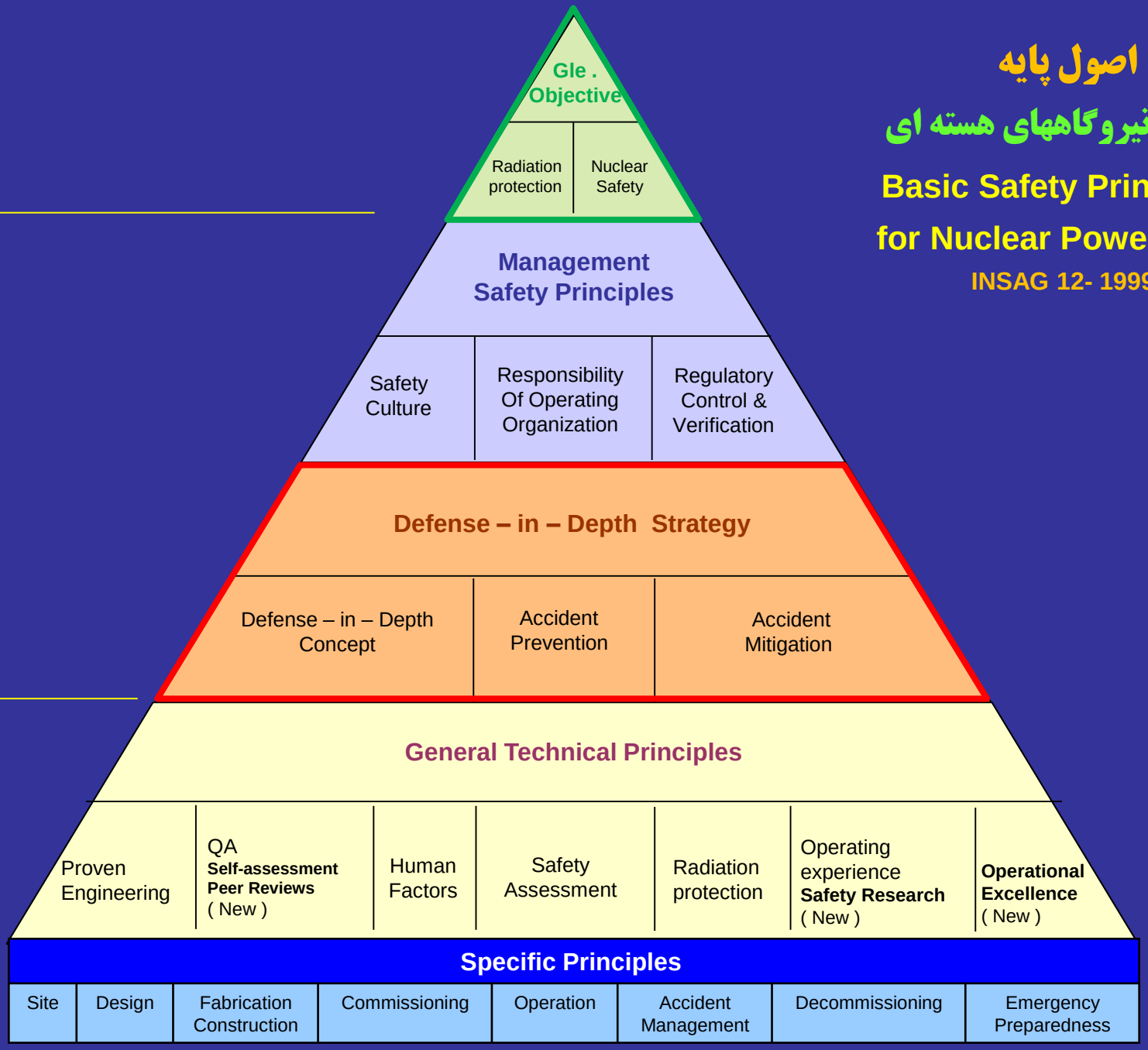


رویکرد پسا فوکوشیما

به طبقه بندی حوادث در نیروگاه هسته ای

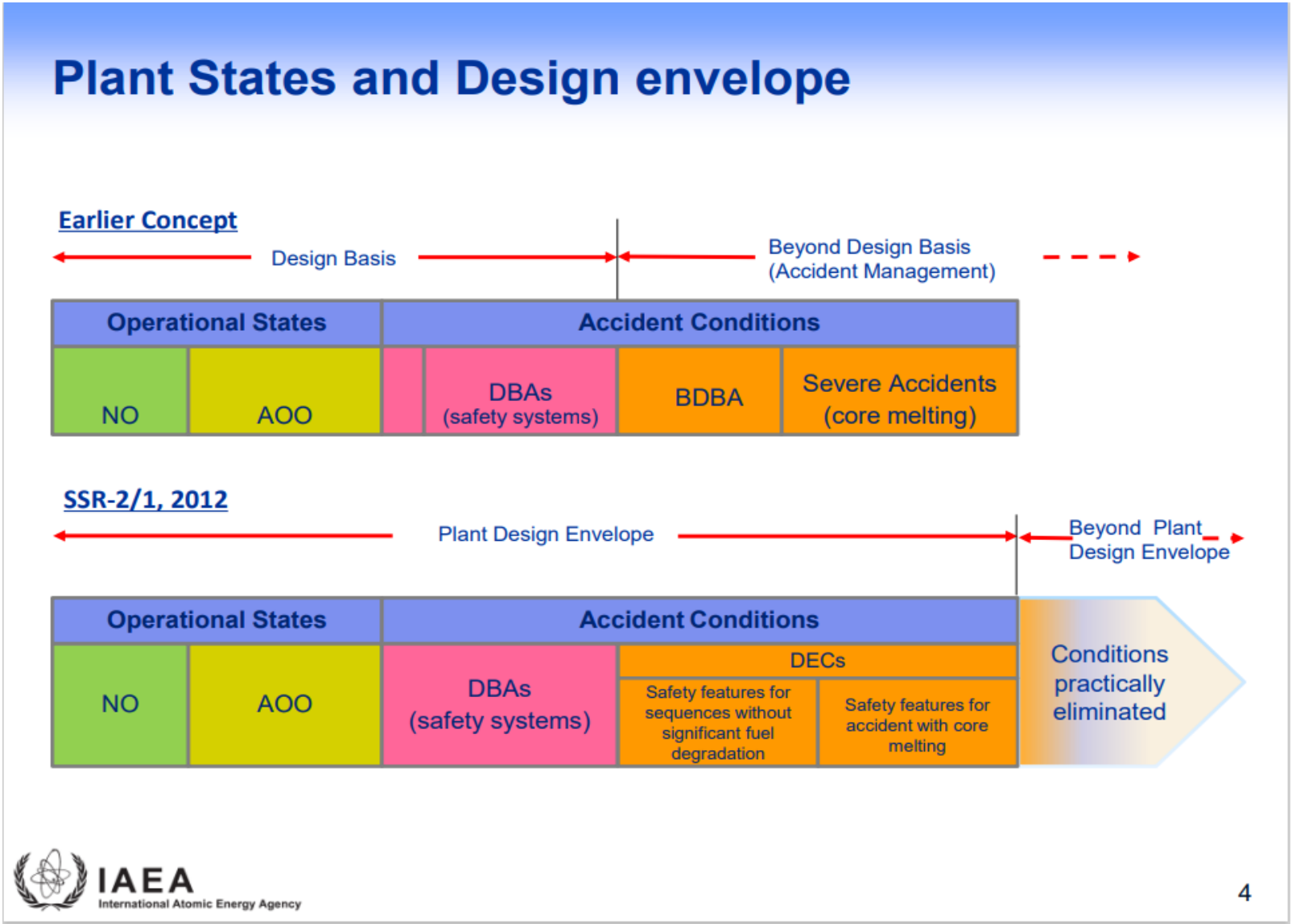
گسترش پوشش حالتهای مختلف نیروگاه در طراحی

TABLE 1. PLANT STATES CONSIDERED IN THE DESIGN

Operational states		Accident conditions		
Normal operation (NO)	Anticipated operational occurrences (AOO)	Design basis accidents (DBA)	Design extension conditions (DEC)	
			without significant fuel degradation	with core melt
	> 10 E-2	10 E-2 - 10 E-6	10E-4 -10E-6	< 10E-6

رویکرد پسا فوکوشیما به طبقه بندی حوادث در نیروگاه هسته ای

گسترش پوشش حالتهای نیروگاه در طراحی



رویکرد پسا فوکوشیما به طبقه بندی حوادث در نیروگاه هسته ای

حوادث عملا قابل حذف

Approach to the Demonstration of Practical Elimination

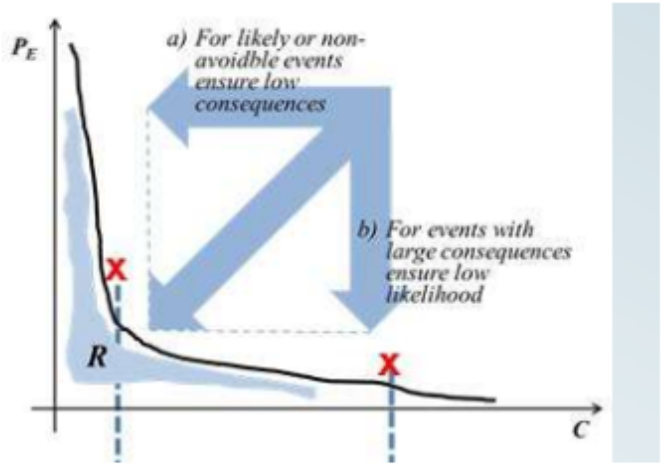
The hypothetical accident conditions that require a specific demonstration of their "practical elimination" include at least following categories:

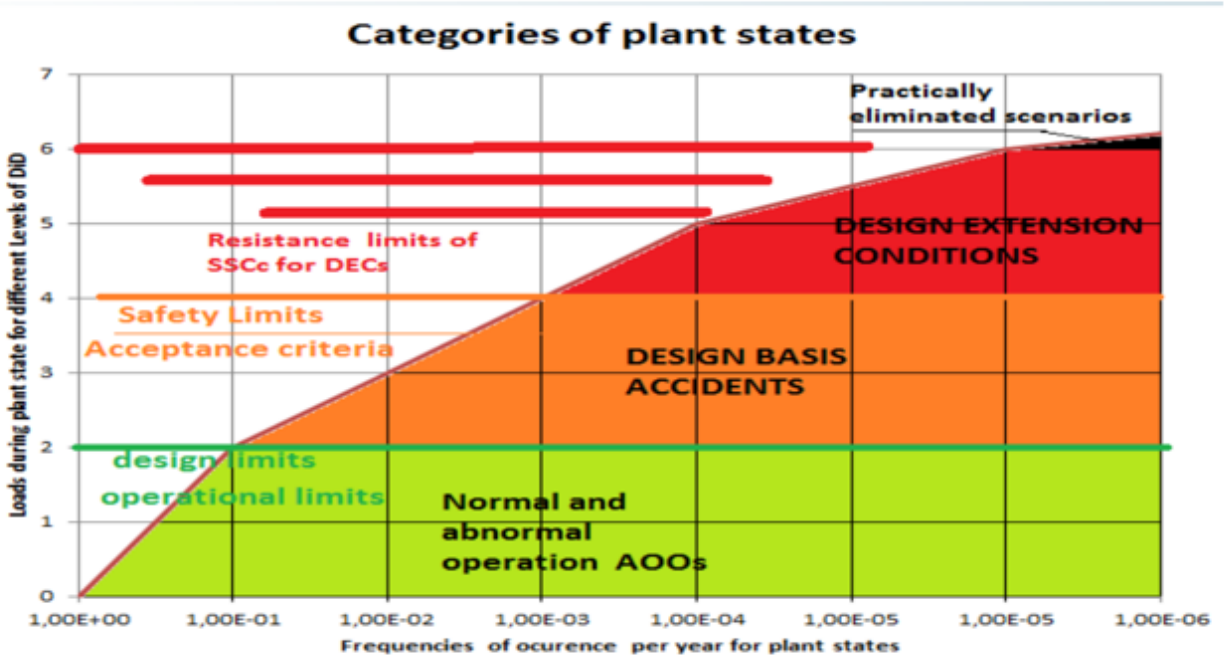
1. **Events that could lead to prompt reactor core damage and consequent early containment failure**
   a. Failure of a large component in the reactor coolant system
   b. Uncontrolled reactivity accidents
2. **Very energetic phenomena in severe accident conditions for which technical solutions for maintaining containment integrity cannot be ensured.**
   a. Core meltdown at high pressure (Direct Containment Heating)
   b. Steam explosion
   c. Hydrogen explosion
   d. Containment boundary melt-through
   e. Containment failure due to fast overpressurization
3. **Non confined severe fuel damage**
   a. Severe accident with containment by pass.
   b. Significant fuel failure in a storage pool

رویکرد پسا فوکوشیما به طبقه بندی حوادث در نیروگاه هسته ای

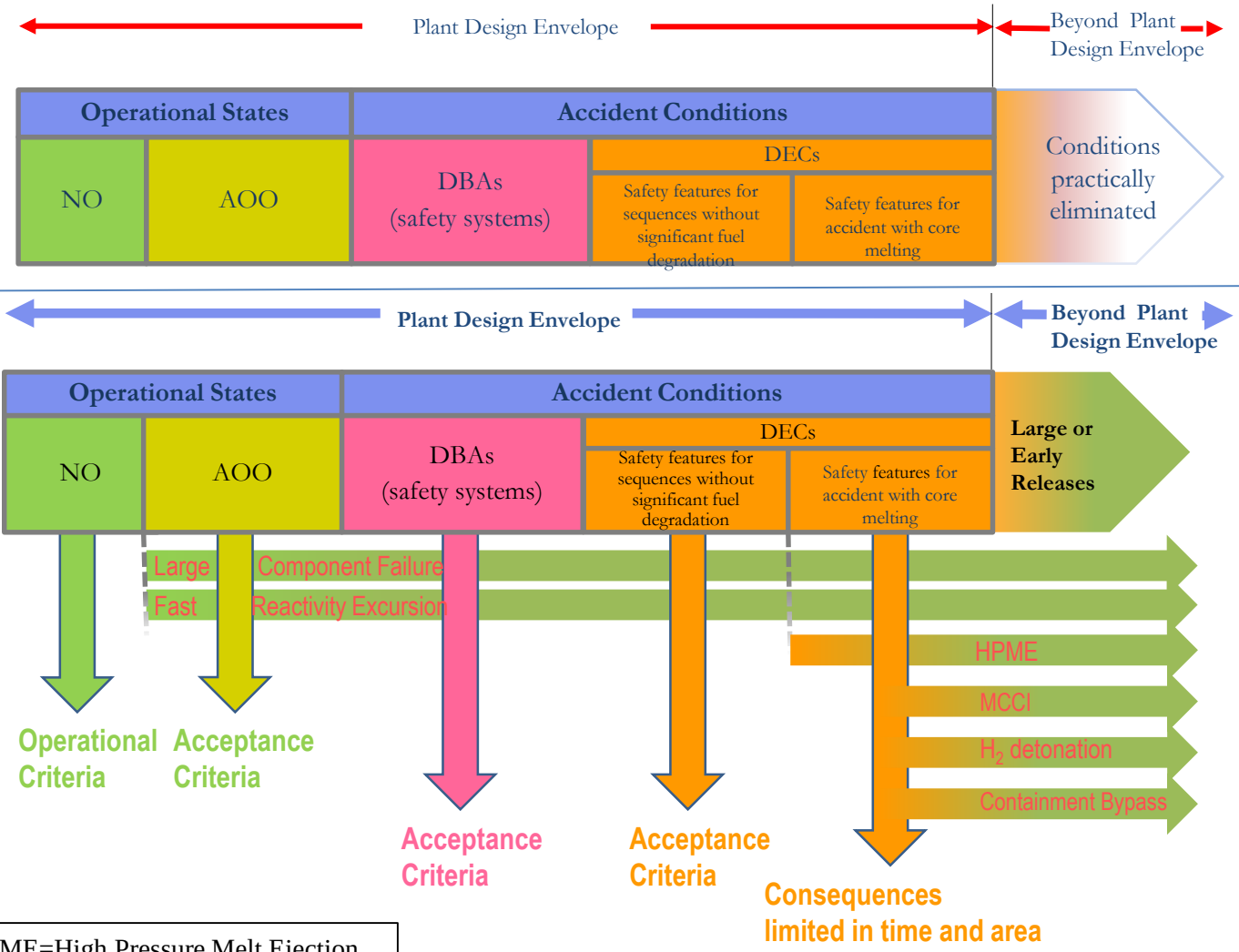
حوادث عملا قابل حذف

THE CONCEPT OF PRACTICAL ELIMINATION





THE CONCEPT OF PRACTICAL ELIMINATION



HPME=High Pressure Melt Ejection

MCCI=Molten Core Concrete Interaction

رویکرد پسا فوکوشیما به طبقه بندی حوادث در نیروگاه هسته ای

مبانی طراحی سازه ها ، سیستم ها و تجهیزات ، برای وضعیت های مختلف نیروگاه

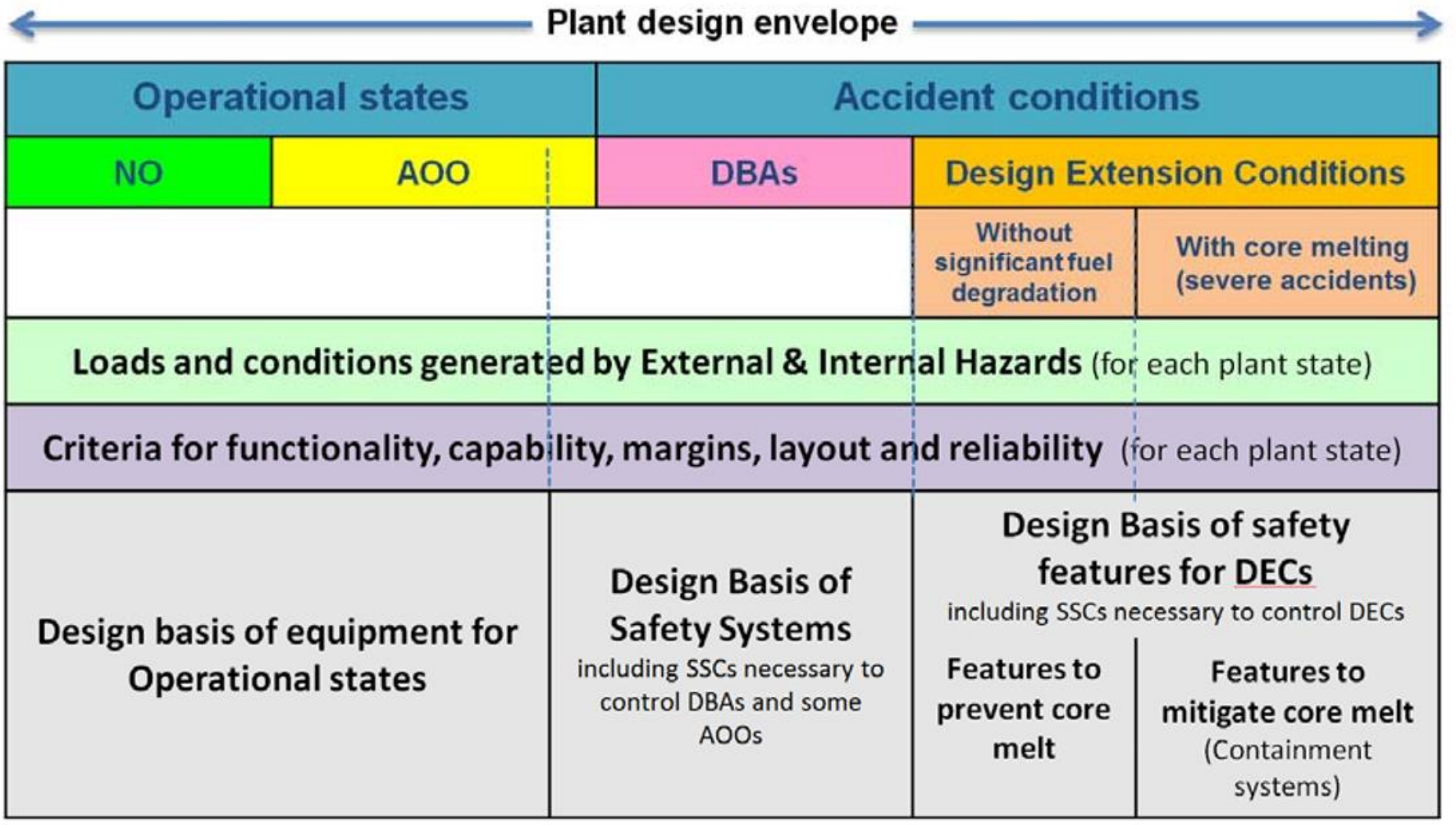


FIG. 2. Main elements of the design basis of SSCs for different plant states.

رویکرد پسا فوکوشیما به طبقه بندی حوادث در نیروگاه هسته ای

قبل از فوکوشیما

Plant States

Operational State		Accident Conditions	
Normal Operation	Anticipated Operational Occurrence	Design Bases Accident	Beyond Design Bases Accident (BDBA)
NO	AOO	DBA	Without significant Core Damage / Severe Accident
	10E-2	10E-6	Rare

بعد از فوکوشیما

Plant design envelope

Operational states		Accident conditions	
NO	AOO	DBAs	Design Extension Conditions
			Without significant fuel degradation / With core melting (severe accidents)
Loads and conditions generated by External & Internal Hazards (for each plant state)			
Criteria for functionality, capability, margins, layout and reliability (for each plant state)			
Design basis of equipment for Operational states	Design Basis of Safety Systems including SSCs necessary to control DBAs and some AOOs	Design Basis of safety features for DECs including SSCs necessary to control DECs	Features to prevent core melt / Features to mitigate core melt (Containment systems)

رویکرد پسا فوکوشیما به طبقه بندی حوادث در نیروگاه هسته ای

رویکرد جدید به سیستمهای ایمنی

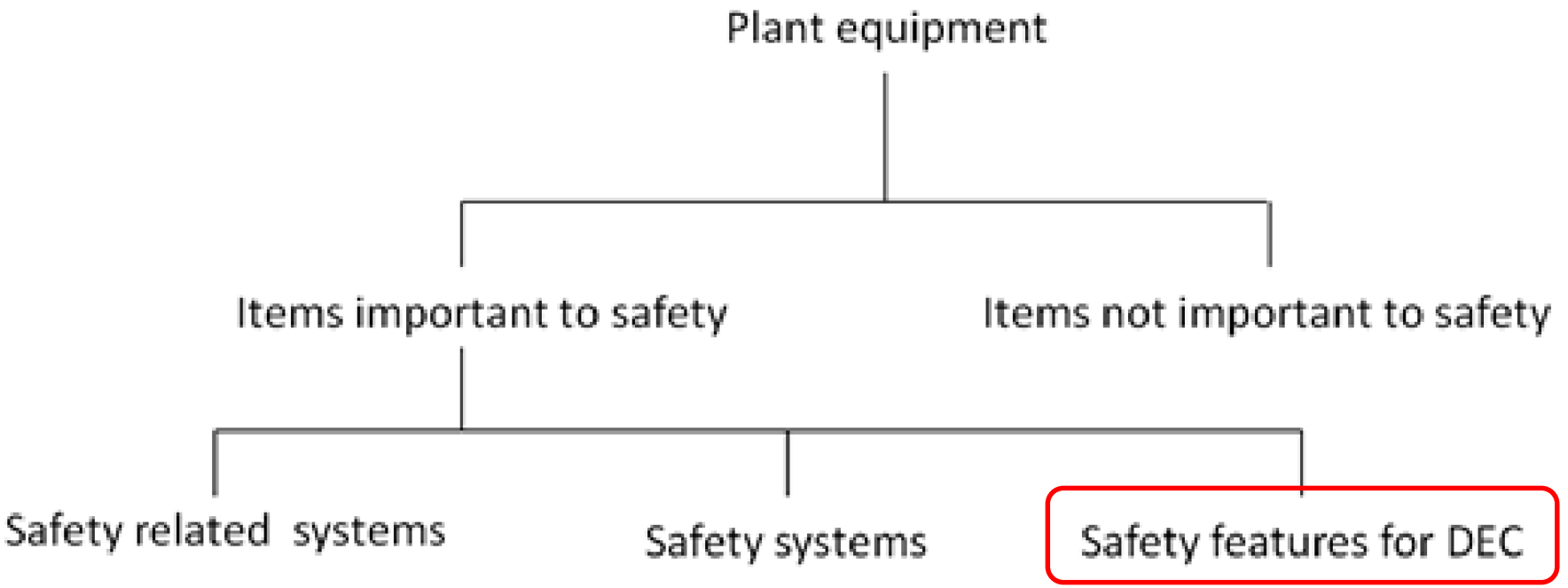


FIG. 1. Plant equipment.

رویکرد پسا فوکوشیما به طبقه بندی حوادث در نیروگاه هسته ای

حاشیه های ایمنی و شرایط پرتگاهی

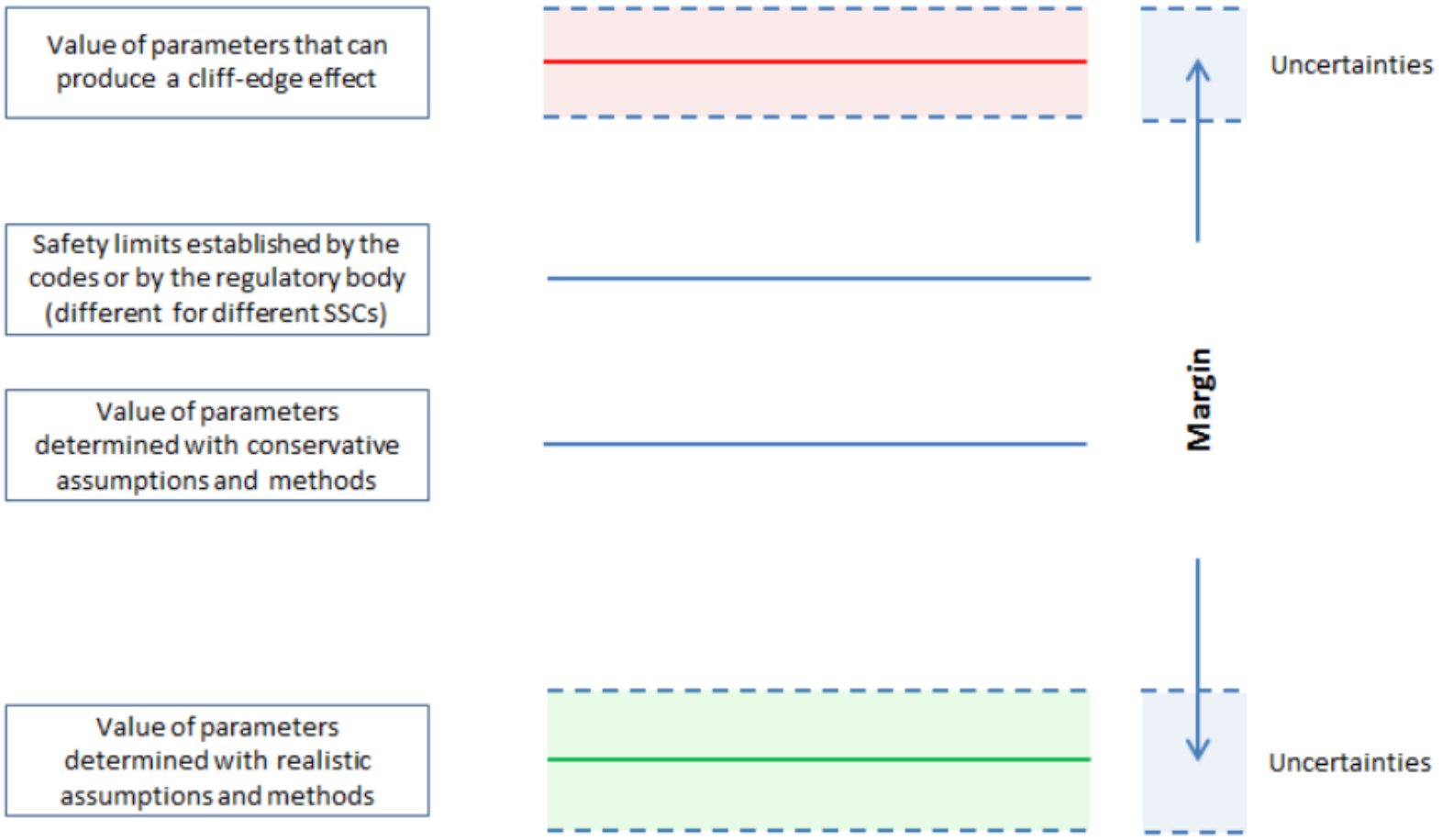


FIG. 3. Margin (safety margin) and cliff edge effects.

CONSIDERATIONS FOR BEYOND DESIGN BASIS EXTERNAL HAZARDS IN NPP SAFETY ANALYSIS ,Transactions, SMiRT-23 , 2015

Table 1. Factors to consider in safety margin determination for External hazards for a hypothetical site/plant

Hazard/Criterion	Fault Disp.	Seismic Ground Motion	Coastal flood	River Flood	Tornadoes	ACC	Explosions	Volcanoes
Cliff Edge	2	1	5	4	3	3	3	3
Lack of Warning	2 (*)	1 (*)	2	3	2	3	5	3
Uncertainties	4	4	4	3	4	2	2	4
Insufficient experience	4	1	3	2	3	3	3	4
Combination	3	4	4	3	2	1	1	3
Concomitant	3	4	4	3	3	4	3	4
Extent of Common Cause	2	5	5	4	3	2	2	5
TOTAL	**20**	**20**	**27**	**22**	**20**	**18**	**19**	**26**

(*) Assuming an automatic seismic scram system is installed, otherwise these may be 3 – 5.

فهرست مطالب

رویکرد های پسا فوکوشیما
به مفهوم دفاع در عمق

IAEA-DiD approach of SSR-2

Level of defence Approach 1	Objective	Essential design means	Essential operational means	Level of defence Approach 2
Level 1	Prevention of abnormal operation and failures	Conservative design and high quality in construction of normal operation systems, including monitoring and control systems	Operational rules and normal operating procedures	Level 1
Level 2	Control of abnormal operation and detection of failures	Limitation and protection systems and other surveillance features	Abnormal operating procedures/emergency operating procedures	Level 2
3a	Control of design basis accidents (postulated single initiating events)	Engineered safety features (safety systems)	Emergency operating procedures	Level 3
Level 3 3b	Control of design extension conditions to prevent core melting	Safety features for design extension conditions without core melting	Emergency operating procedures	4a
Level 4	Control of design extension conditions to mitigate the consequences of severe accidents	Safety features for design extension conditions with core melting. Technical Support Centre	Complementary emergency operating procedures/ severe accident management guidelines	Level 4 4b
Level 5	Mitigation of radiological consequences of significant releases of radioactive materials	On-site and off-site emergency response facilities	On-site and off-site emergency plans	Level 5

رویکرد های پسا فوکوشیما به راهبرد دفاع در عمق

مقایسه رویکرد ها بعد از حوادث هسته ای وخیم

بعد از چرنوبیل

TABLE I. LEVELS OF DEFENCE IN DEPTH IN EXISTING PLANTS

Levels	Objective	Essential means
Level 1	Prevention of abnormal operation and failures	Conservative design and high quality in construction and operation
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بعد از فوکوشیما

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رویکرد های پسا فوکوشیما به راهبرد دفاع در عمق

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رویکرد های پسا فوکوشیما به راهبرد دفاع در عمق

مقایسه رویکرد ها بعد از حوادث هسته ای وخیم

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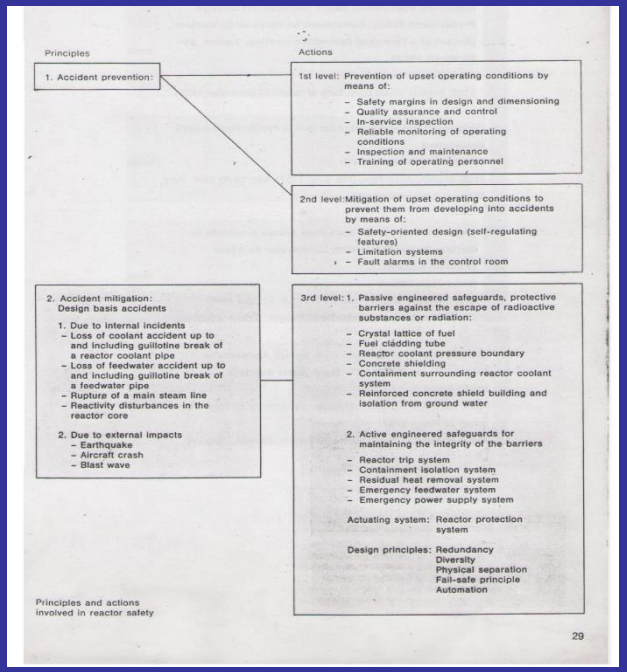

بعد از چرنوبیل

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بعد از فوکوشیما

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TABLE 5. EXAMPLES OF ACCEPTANCE CRITERIA FOR DIFFERENT PLANT STATES

Level of defence	Objective	Associated plant state	Criteria for maintaining integrity of barriers	Criteria for limitation of radiological consequences
Level 1	Prevention of abnormal operation and failures	Normal operation	No failure of any of the physical barriers except minor operational leakages	Negligible radiological impact beyond immediate vicinity of the plant. Acceptable effective dose limits are bounded by the general radiation protection limit for the public (1 mSv /year[20] commensurate with typical doses due to natural background), typically in the order of 0.1 mSv/year.
Level 2	Control of abnormal operation and detection of failures	Anticipated operational occurrence	No failure of any of the physical barriers except minor operational leakages	Negligible radiological impact beyond immediate vicinity of the plant. Acceptable effective dose limits are similar as for normal operation, limiting the impact per event and for the period of 1 year following the event (0.1 mSv/y)
Level 3a	Control of design basis accidents (DBAs)	Design basis accident	No consequential damage of the reactor coolant system, maintaining containment integrity, limited damage of the fuel	No or only minor radiological impact beyond immediate vicinity of the plant, without the need for any off-site emergency actions. Acceptable effective dose limits are typically in the order of few mSv.
Level 3b	Control of DECs without significant fuel degradation (prevention of accident progression into severe accident)	Design extension condition without significant fuel degradation	No consequential damage of the reactor coolant system, maintaining containment integrity, limited damage of the fuel.	The same or similar radiological acceptance criteria as for the most unlikely design basis accidents
Level 4	Control of DECs with core melt (mitigation of consequences of severe accidents)	Design extension condition with core melt (severe accident)	Maintaining containment integrity	Only emergency countermeasures that are of limited scope in terms of area and time are necessary[21]
Level 5	Mitigation of radiological consequences of significant releases	Accident with releases requiring implementation of emergency countermeasures	Containment integrity severely impacted, or containment disabled or bypassed	Off-site radiological impact necessitating emergency countermeasures

رویکرد های پسا فوکوشیما
به مفهوم دفاع در عمق
معیارهای پذیرش
برای
حالتهای مختلف نیروگاه
IAEA Approach

رویکرد های پسا فوکوشیما به راهبرد دفاع در عمق

رویکرد آلمان

3. GERMAN DEFENCE IN DEPTH CONCEPT

Internationally, the defence in depth concept consists of five subsequent levels [4-8]. The Safety Requirements for existing nuclear power plants published in 2013 define a sophisticated defence in depth concept for German NPPs. It is characterized by the first four levels of defence in depth:

- Level 1: normal operation;
  Level 2: abnormal operation;
- Level 3: design basis accidents;
- Level 4: design extension conditions;
  - Level 4a: ATWS;
  - Level 4b: multiple failure of safety system;
  - Level 4c: accidents with severe fuel assembly damages.

رویکرد های پسا فوکوشیما به راهبرد دفاع در عمق

رویکرد آلمان

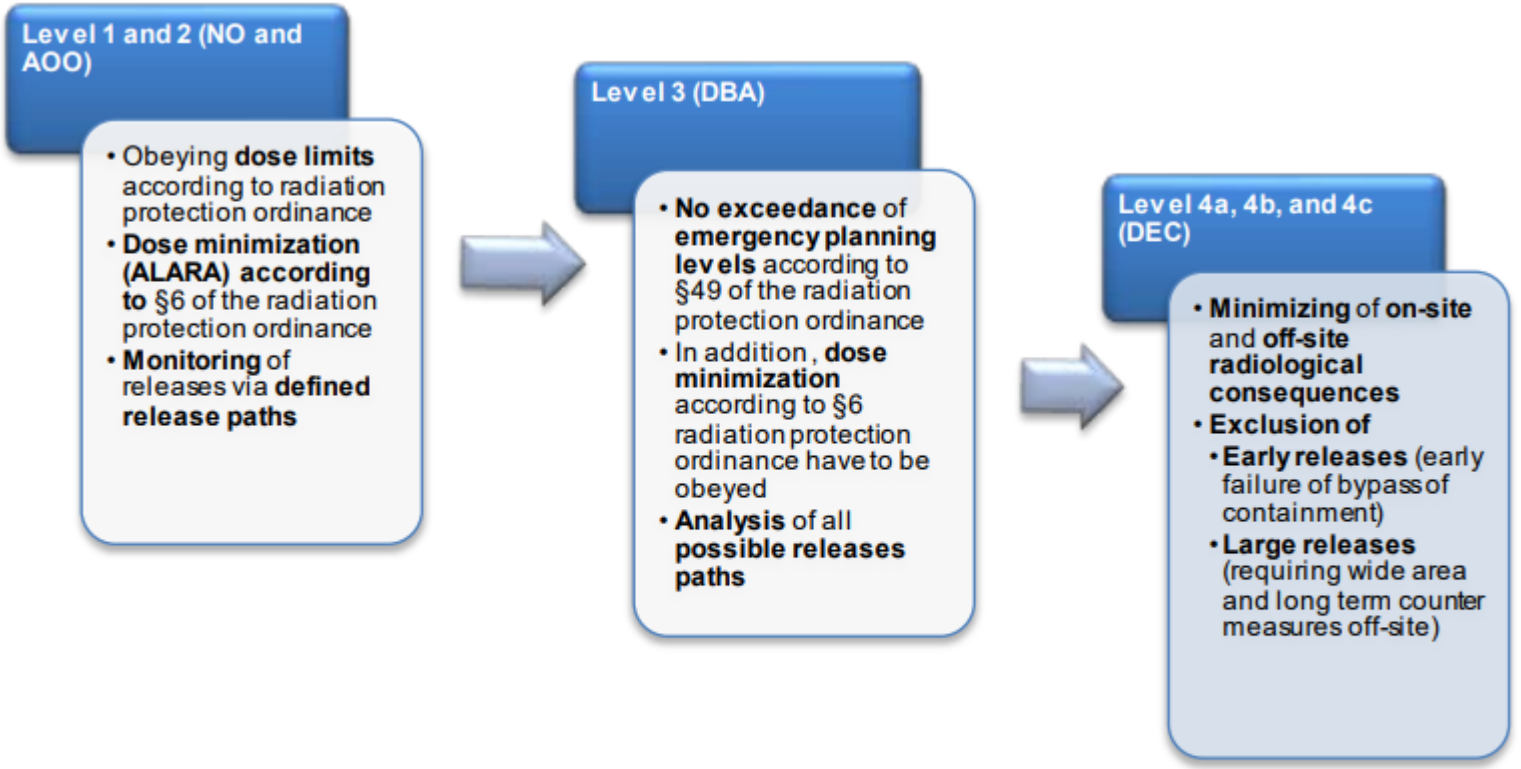

FIG. 1. Radiological safety objectives on different levels of defence in depth in Germany.

رویکرد های پسا فوکوشیما به راهبرد دفاع در عمق

رویکرد آلمان

TABLE 1 REQUIRED BARRIERS ON DIFFERENT LEVELS OF DEFENCE IN DEPTH FOR FUEL IN THECORE AND STORED IN THE SPENT FUEL POOL

<table>
<tr><th></th><th>Fuel in the core</th><th>Spent fuel pool</th></tr>
<tr><td>Level 1
Level 2</td><td>• Fuel cladding
• Pressure retaining wall
• Containment</td><td>• Fuel cladding
• Containment / compensating retention function</td></tr>
<tr><td>Level 3</td><td>• Fuel cladding
• Pressure retaining wall
• Containment</td><td>• Fuel cladding
• Containment / compensating retention function</td></tr>
<tr><td>Level 4a</td><td>• Fuel cladding
• Pressure retaining wall
• containment</td><td></td></tr>
<tr><td>Level 4b</td><td colspan="2">At least on barrier</td></tr>
<tr><td>Level 4c</td><td colspan="2">Maintaining the integrity of the containment as long as possible
In case of fuel elements stored outside a containment: Maintaining the integrity of the surrounding building as long as possible</td></tr>
</table>

رویکرد های پسا فوکوشیما به راهبرد دفاع در عمق

مقایسه رویکرد آلمان با رویکرد آژانس

	Plant states					
Level	existing NPP			new NPP		
1	Normal operation		Normal operation	Normal operation		Normal operation
2	Abnormal operation		AOO	AOO		AOO
3	Accidents (DBA)		DBA	3a	Postulated singel initating events	DBA
4	4a	Very rare events	DEC without core melt	3b	Postulated multiple failure events	DEC without significant fuel degradation
	4b	Events involving multiple failure of safety equipment				
	4c	Accidents involving severe fuel assembly damages	DEC with core melt	4	Postulated core melt accidents	DEC with core melt
5	Off-site emergency response					

FIG. 2. Comparison German defence in depth concept with IAEA and WENRA approaches.

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1. اصول پایه و اصول بنیادی ایمنی هسته ای
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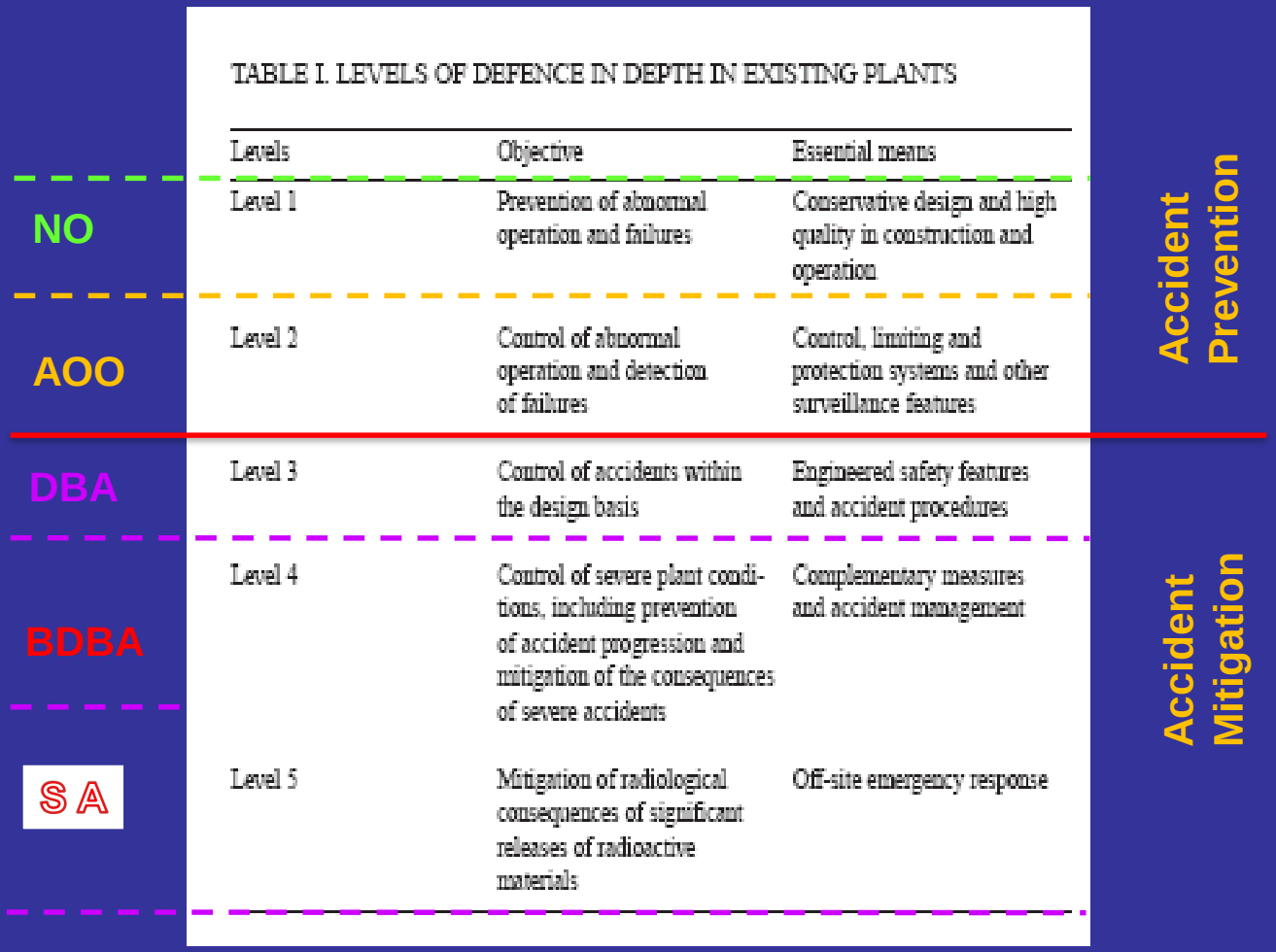
رویکرد های پسا فوکوشیما به مفهوم دفاع در عمق

اصول پیشگیری و مهار حوادث قبل از فوکوشیما



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رویکرد های پسا فوکوشیما به مفهوم دفاع در عمق

اصول پیشگیری و مهار حوادث پس از فوکوشیما

Normal Operation

Sever Accidents

Level of defence Approach 1	Objective	Essential design means	Essential operational means	Level of defence Approach 2
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Accident Prevention

Accident Mitigation

References

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2. IAEA-Safety of Nuclear Power Plants: Design , Specific Safety Requirements INTERNATIONAL ATOMIC ENERGY AGENCY VIENNA ISBN 978–92 –0–109315–8 ISSN 1020–525X No. SSR-2/1 (Rev. 1) , 2016

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K. NÜNIGHOFF Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH Cologne, 2015 Germany Email: kay.nuenighoff@grs.de

5. CONSIDERATIONS FOR BEYOND DESIGN BASIS EXTERNAL HAZARDS IN NPP SAFETY ANALYSIS, Aybars Gürpinar1 , Antonio R. Godoy, James J. Johnson2,
Transactions, SMiRT-23 Manchester, United Kingdom - August 10-14, 2015 Division IV,ID 424

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سخن پایانی

لِکُلِّ شَیءٍ طَریقٌ ، و طَریقُ الجَنَّةِ العِلمُ

برای هر چیز راهی است ، و راه بهشت علم است

حدیث نبوی