International Atomic Energy Agency

SASI WS 2-09

Experience Sharing on Safety Assessments

Example from other industry International Atomic Energy Agency

Nicolas TRICOT –NSNI/SAS

June 11-12, 2009 – Eurocontrol - Brussels

OUTLINE

- **Introduction**
- **The IAEA Safety Standards (structure, hierarchy, application)**
  - **Safety fundamentals**
  - **Safety requirements**
  - **Safety guides**
  - **Safety series, Tec Docs**
- **Safety of Nuclear Power Plants : Design (NS-R1)**
- **Safety assessment for facilities and activities (GS-R-4)**
  - **Overall content**
  - **Selected examples vs. Generic Reactor Safety Reviews (GRSR)**
  - **Main findings**
- **Concluding remarks**

INTRODUCTION
Global context

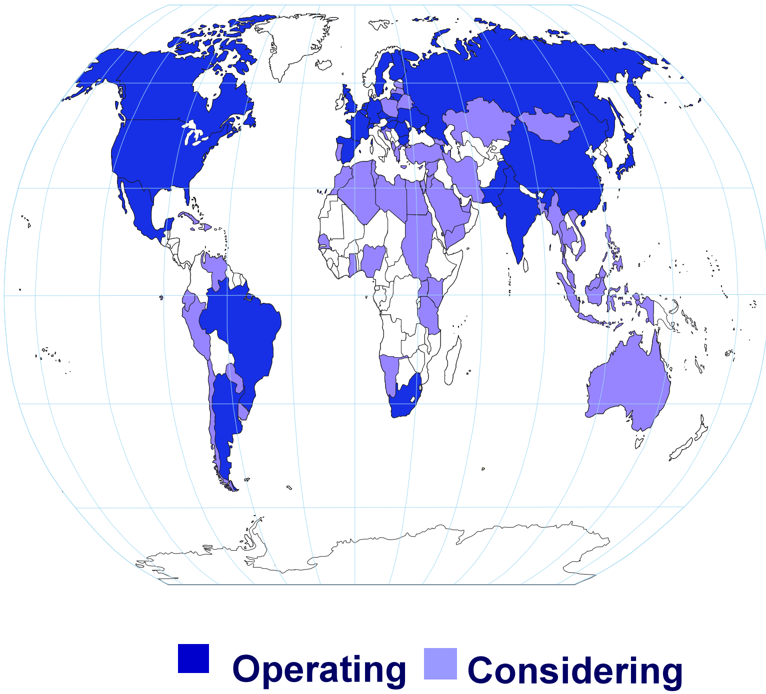
- Fossil price rise
- Stable, competitive energy
- Energy supply security
- Environment

INTRODUCTION
World trend

- **Renewed interest for nuclear energy**

- **projected number of new countries starting operation of NP**
  - **8 by 2020**
  - **23 by 2030 in high projection**
  - **growth estimate from 20% to 90% by 2030**

- **different country situation**
  - **countries having stopped construction but willing to resume soon,**
  - **countries having never stopped NPP construction,**
  - **nuclear power newcomers**



INTRODUCTION
What does the IAEA do?

- **General Guidance**

- **"MILESTONES in the Development of a National Infrastructure for Nuclear Power,** NE series guide NG-G-3.1, September 2007
- **"CONSIDERATION to launch a nuclear power programme"** Brochure March 2007

- **Safety Standards**

- **SF-1 "Fundamental Safety Principles"**
- **Requirements and guides**

INTRODUCTION
What does the IAEA do?

- **Services**

  - **Global guidance at early stages**
  - **Facilitating competence building (staffing, identification of training needs, training)**
  - **Assessment of the current status of the Governmental and regulatory framework and recommendations (Laws, regulations, rules and Regulatory Body's activities)**
  - **Expert missions to review design aspects, feasibility study, site survey, site evaluation, construction, commissioning and operation**
  - **Peers reviews to assess Safety Standards' uses (GRSR)**

THE IAEA SAFETY STANDARDS

STRUCTURE OF SAFETY RELATED DOCUMENTS

SAFETY STANDARD SERIES

Fundamentals (1)

Principles

Requirements (15)

“Shall”

Guides (120)

“Should”

SAFETY REPORTS, TECDOCs, etc.

(Present applications, good practices, etc.)

APPLICATION OF THE IAEA SAFETY STANDARDS

- Although the IAEA Safety Standards (SS) are recognized internationally, the degree of recognition varies significantly

- Big change is expected on further use and application of IAEA Safety Standards by Member States as:

    - many MS started or will start a review process of their national Safety Requirements and a comparison between the new IAEA SS and their existing national SS

    - the nuclear renaissance will lead to license new reactors designs worldwide (importance of the safety reviews against IAEA safety standards)

    -

- IAEA trend to

    - continue the development of safety standards (preferably to Tec Docs)
    - use a technology neutral approach in developing or updating the safety standards

OVERVIEW OF THE IAEA SAFETY STANDARDS

THE SAFETY STANDARDS COVER SAFETY IN FIVE AREAS

- **NS** Safety of nuclear facilities
- **RS** Radiation protection and safety of radiation
- **WS** Safe management of radioactive waste
- **TS** Safe transport of radioactive material
- **GS** General safety (cross-cutting themes)

Thematic areas

- Legal and governmental infrastructure
- Emergency preparedness and response
- Management systems
- Assessment and verification
- Site evaluation
- Radiation protection
- Radioactive waste management
- Decommissioning
- Rehabilitation of contaminated areas

Facilities and activities

- Nuclear power plants
- Research reactors
- Fuel cycle facilities
- Radiation related facilities and activities
- Waste treatment and disposal facilities
- Transport of radioactive material

IAEA Safety Standards are available on: **www.iaea.org**

HIERARCHY OF THE IAEA SAFETY STANDARDS SERIES

Basic objectives, concepts and principles to ensure safety

FUNDAMENTAL SAFETY PRINCIPLES

Requirements which must be satisfied to ensure safety

"Shall Statements"

- SAFETY OF NUCLEAR POWER PLANTS: DESIGN (SSS No. NS-R-1)
- SAFETY OF NUCLEAR POWER PLANTS:OPERATION (SSS No. NS-R-2)
- SITE EVALUATION FOR NUCLEAR INSTALLATIONS SAFETY REQUIREMENTS (SSS No. NS-R-3)
- SAFETY ASSESSMENT FOR FACILITIES AND ACTIVITIES (SSS No. GS-R4 - Draft)

- SAFETY GUIDES NS G-1-X
- SAFETY GUIDES NS G-2-X
- SAFETY GUIDES NS G-3-X
- SAFETY GUIDES NS G-4-X

Recommended actions, conditions or procedures for meeting safety requirements

"Should Statements"

STATUS OF DEVELOPMENT OF IAEA SAFETY STANDARDS ON SAFETY ANALYSIS AND ACCIDENT MANAGEMENT

SAFETY OF NUCLEAR POWER PLANTS: DESIGN (SSS No. NS-R-1)

SAFETY ASSESSMENT FOR FACILITIES AND ACTIVITIES (SSS No. GS-R4 - Draft)

Deterministic Safety Analysis and Applications for Nuclear Power Plants	Development and Application of Level 1 PSA for Nuclear Power Plants	Development and Application of Level 2 PSA for Nuclear Power Plants	Severe Accident Management Programme for Nuclear Power Plants	Safety Goals	Safety Classification of Structures, Systems and Components (technology neutral) Draft
(DS 395)	(DS394)	(DS393)	(DS385)	(not drafted)	NS-G 1.14

IAEA Service : Generic Reactor Safety Reviews

UK EPR, ESBWR, AP1000

France/Japan ATMEA1

USA AP1000

Korea APR1400

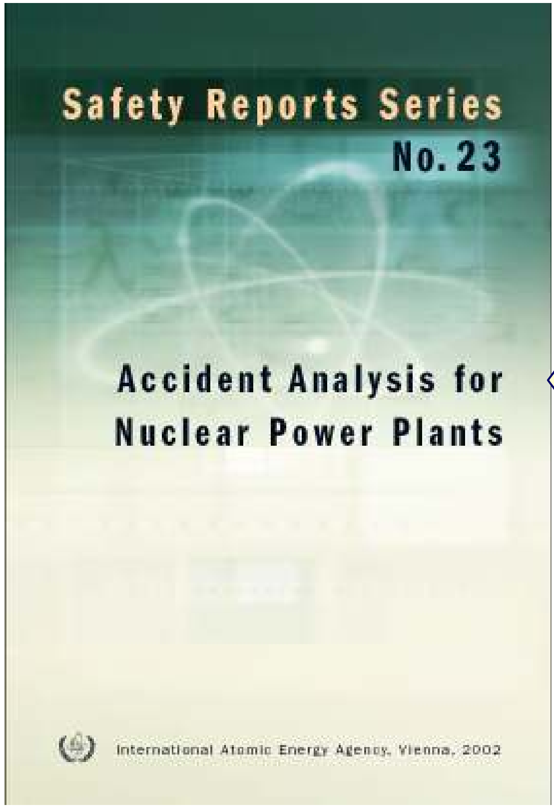
SAFETY REPORTS, TECDOCs, etc. ***(Present applications, good practices, etc.)***

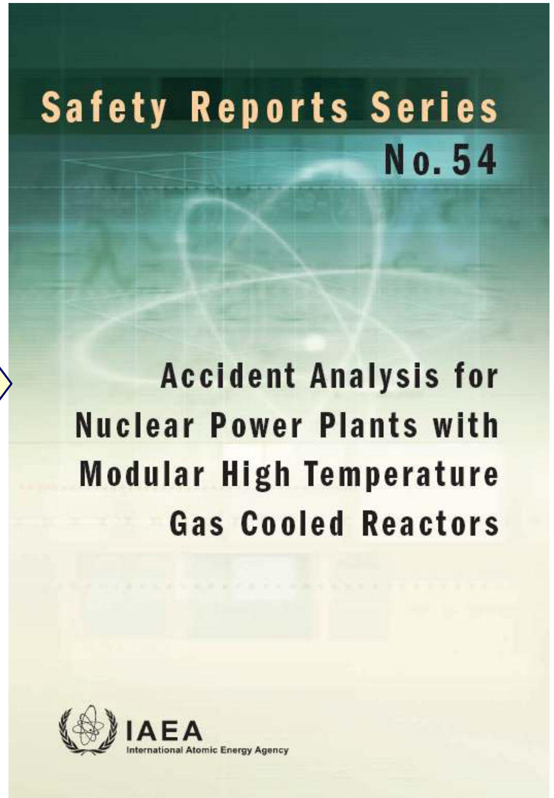
Ref: http://www-ns.iaea.org/standards/documents/pubdoc-list.asp

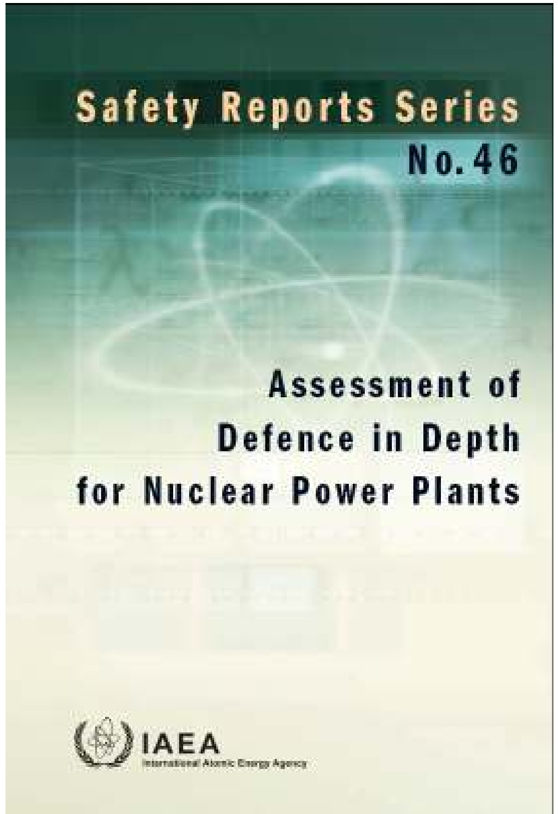
EXAMPLES OF SAFETY STANDARDS RELATED DOCUMENTS IN THE AREA OF SAFETY OF NUCLEAR INSTALLATIONS

Ref: http://www-ns.iaea.org/standards/documents/pubdoc-list.asp

IAEA DOCUMENTS RELATED TO SAFETY







Ref: http://www-ns.iaea.org/standards/documents/pubdoc-list.asp

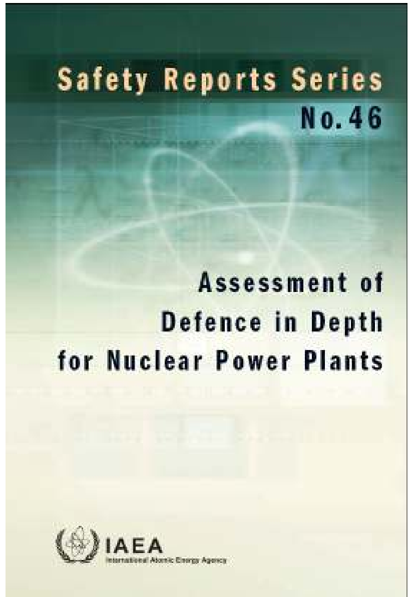
SAFETY OF NPPS: DESIGN (NS-R-1)

- **Published in 2000, mainly devoted to LWRs**
- **Based on best practices worldwide at the time:**
  - **Deterministic safety assessment (DSA) plays a major role in demonstrating compliance with safety requirements, probabilistic safety assessment (PSA) supports DSA**
  - **Conservative DSA for anticipated operational occurrences and design basis accidents (DBA), best estimate (BE) approach for severe accidents**
  - **No established requirements for governing the selection of postulated initiating events**
    - **Categories of plant states typically cover:**
      - **Normal operation**
      - **Anticipated operational occurrences**
      - **Design basis accidents**
      - **Beyond design basis accidents (Severe accidents)**
    - **Acceptance criteria should be assigned to each category**

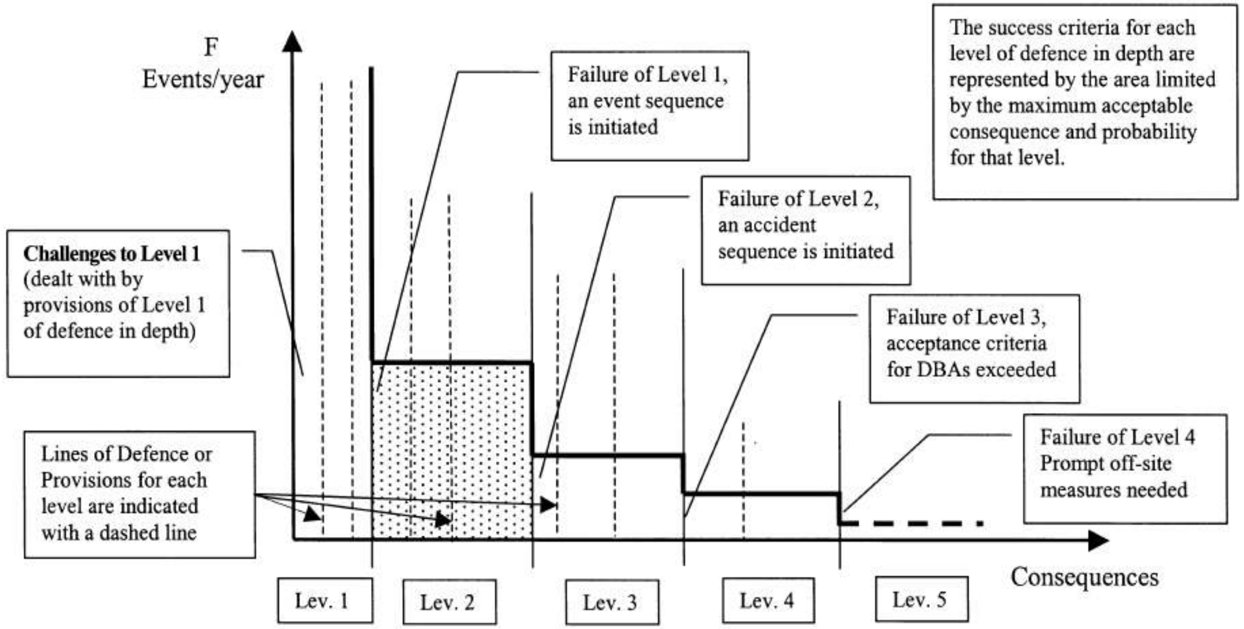
CONCEPT OF DiD

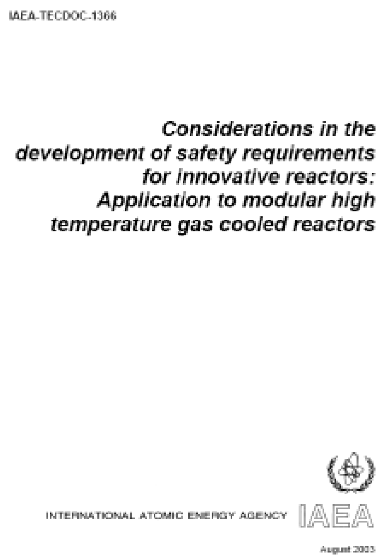
TABLE I. LEVELS OF DEFENCE IN DEPTH (FROM INSAG-10) [9]

Levels of defence	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



LEVELS OF DEFENCE AND SUCCESS CRITERIA




IAEA-TECDOC-1366

Considerations in the development of safety requirements for innovative reactors: Application to modular high temperature gas cooled reactors

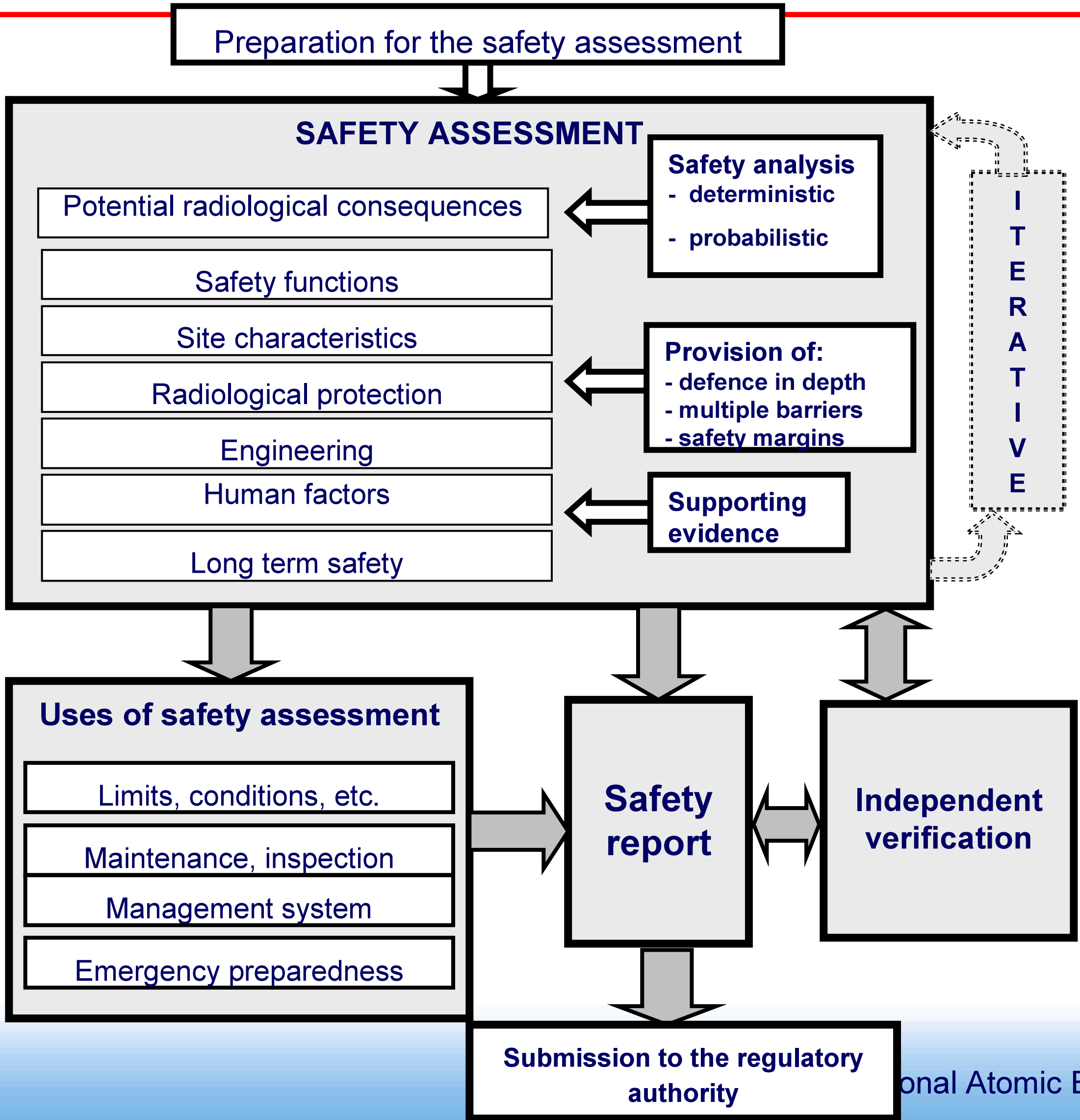
INTERNATIONAL ATOMIC ENERGY AGENCY IAEA

August 2003

SAFETY ASSESSMENT FOR FACILITIES AND ACTIVITIES (GS-R-4)

- **Safety Assessment**
  - The safety assessment shall have the primary purpose of determining whether an adequate level of safety has been achieved for a facility or activity and whether the basic safety objectives and safety criteria established by the designers, the operator and the regulatory authority, reflecting the radiation protection requirements as laid down in the Basic Safety Standard have been complied with.
  - Therefore, (…) requirements are identified to be used in the safety assessment of nuclear facilities and activities with special attention to the defence in depth, quantitative analyses and the application of graded approach considering the range of facilities and activities addressed GS-R-4)
- **Draft is under review by Members States**
  - Intended for application to all facilities (e.g. enrichment and manufacturing plants, NPPs) and activities (e.g. sources and their production, transportation)

SAFETY ASSESSMENT FLOWCHART (GS-R-4)



SAFETY ASSESSMENT AND SAFETY ANALYSIS

Safety assessment

Safety analysis

Two complementary methods

Deterministic Safety Analysis (DSA)

Predicts the response to postulated events with predetermined assumptions; checks fulfilment of acceptance criteria

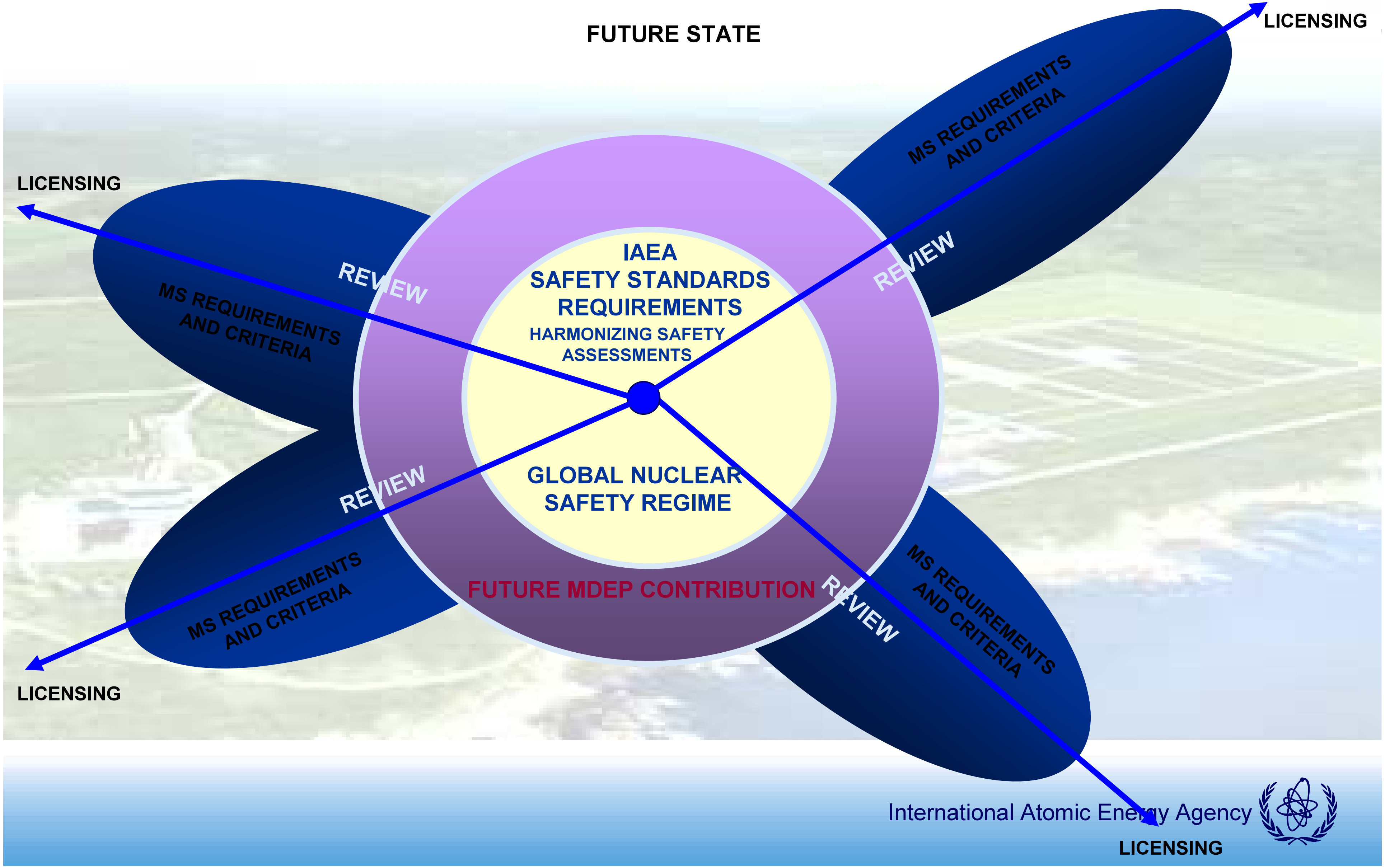
Probabilistic Safety Analysis (PSA)

Combines the likelihood of initiating events, potential scenarios and their consequences into estimation of CFD, source term or overall risk

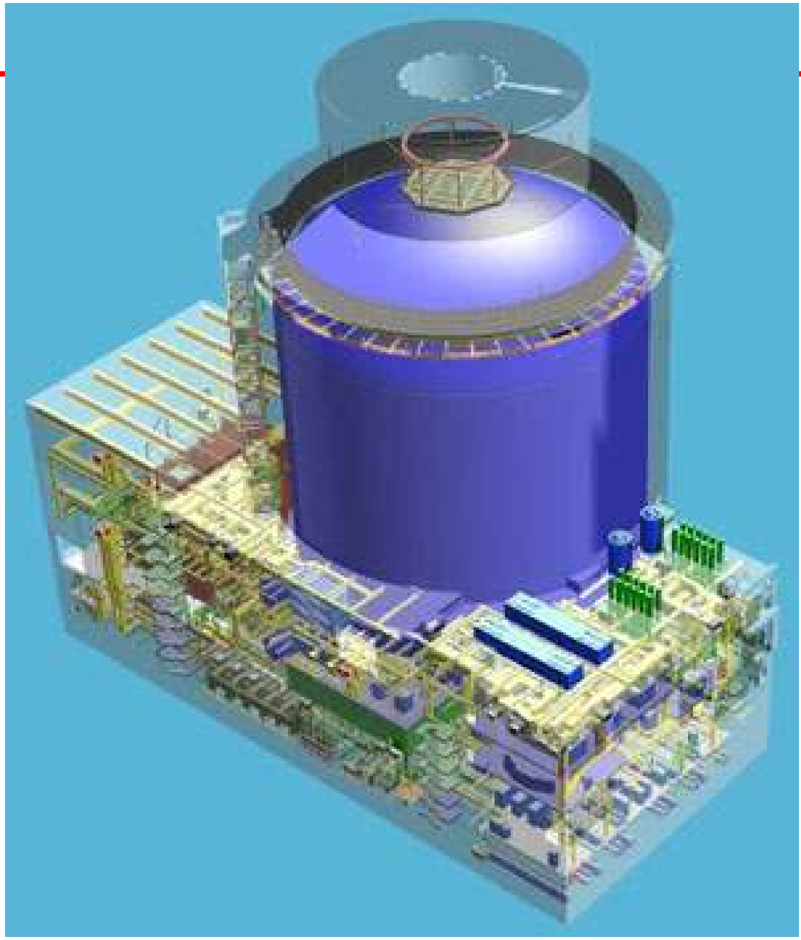
Evaluation of engineering factors important to safety

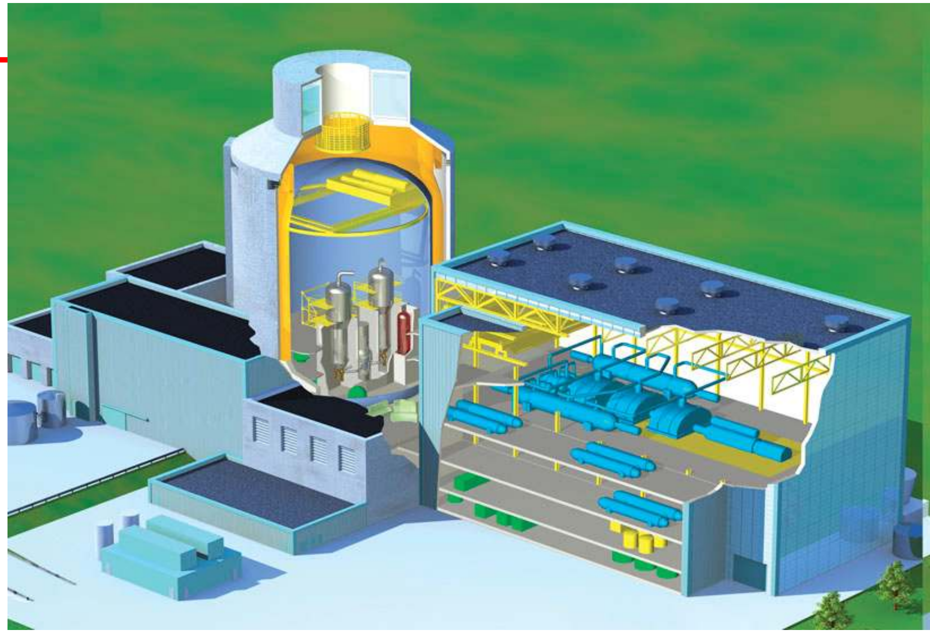
- Proven engineering practices
- Defence in depth
- Radiation protection
- Safety classification
- Protection against internal and external hazards
- Combination of loads
- Selection of materials
- Single failure criterion
- Redundancy, diversity
- Equipment qualification
- Ageing
- Man-machine interface, …

IAEA Safety Requirements and Generic Reactor Safety Review



AP1000





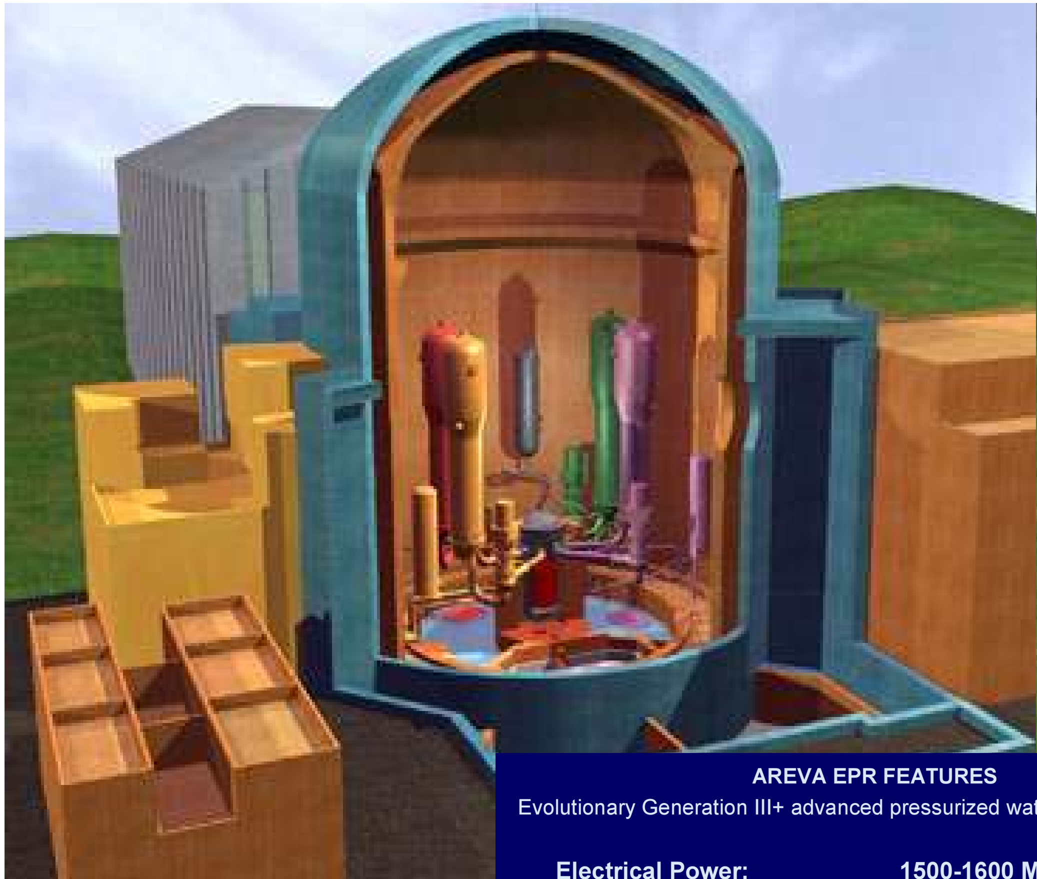
Westinghouse AP 1000

FEATURES: Advanced PWR incorporating passive safety systems and a simplified plant design:

- **Electrical Power: 1.117 MWe**
- **Thermal Output: 3,400 MWt**
- **Plant Life: 60 Years**
- **Fuel Enrichment: < 4.95%**
- **Plant Efficiency: 35.1%/32.7%**
- **Operation Cycle: 18 months**
- **Plant Availability: 93%**

Westinghouse

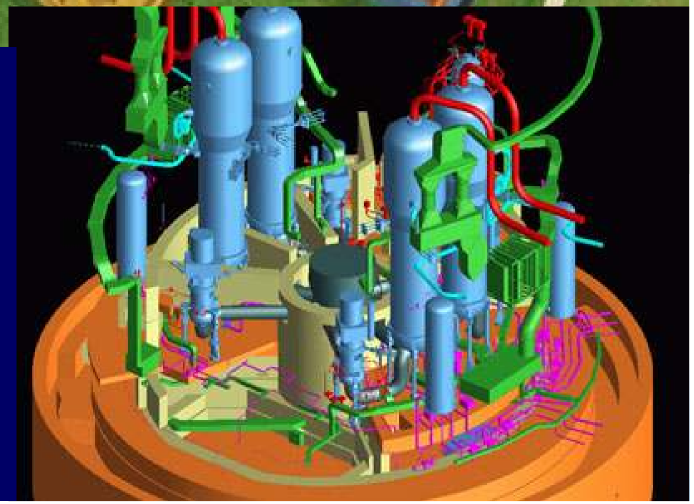
EPR – European Pressurized Water Reactor



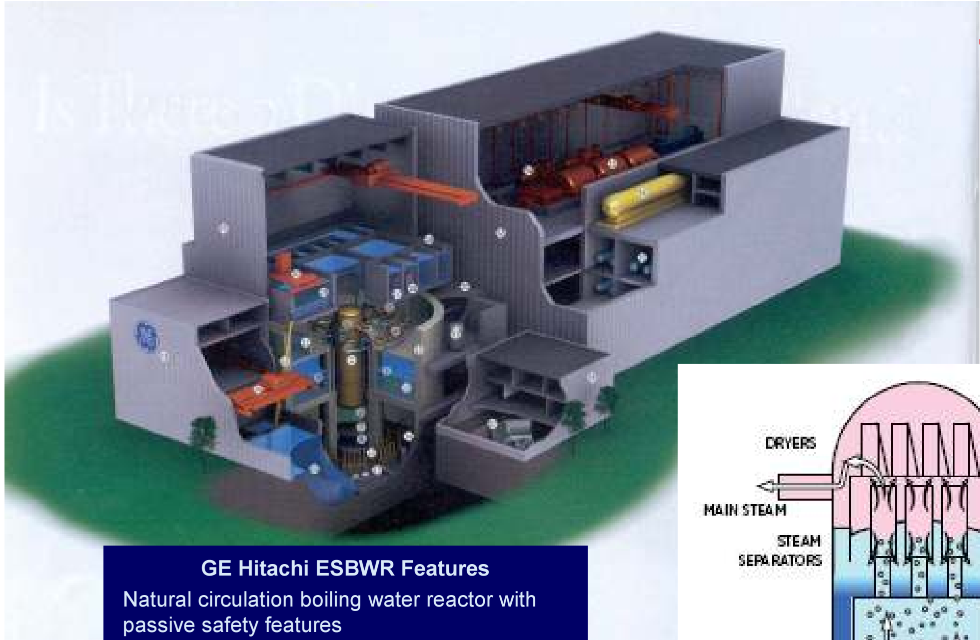
AREVA EPR FEATURES

Evolutionary Generation III+ advanced pressurized water reactor

Electrical Power:	**1500-1600 MWe**
Thermal Power:	**4250/4500 MWt**
Plant Life: 60 Years	
Fuel Enrichment:	**up to 5%**
Plant Efficiency:	**36%**
Operation Cycle:	**up to 24 Months**
Plant Availability:	**91%**



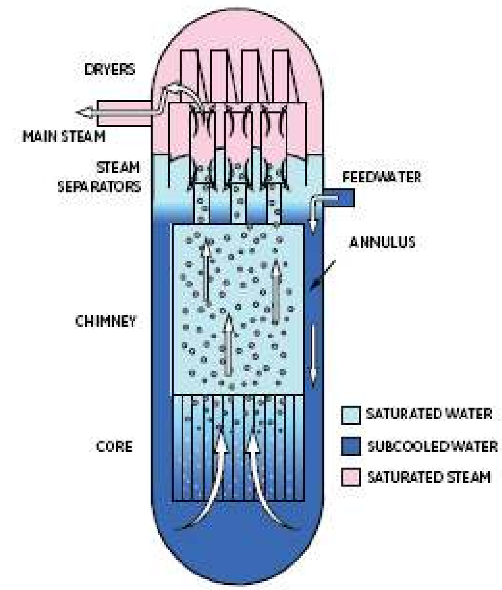
ESBWR – Economic Simplified BWR

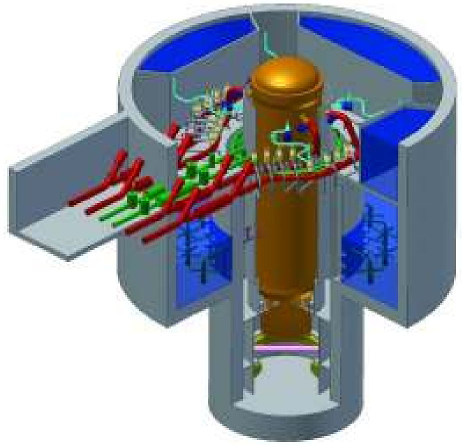


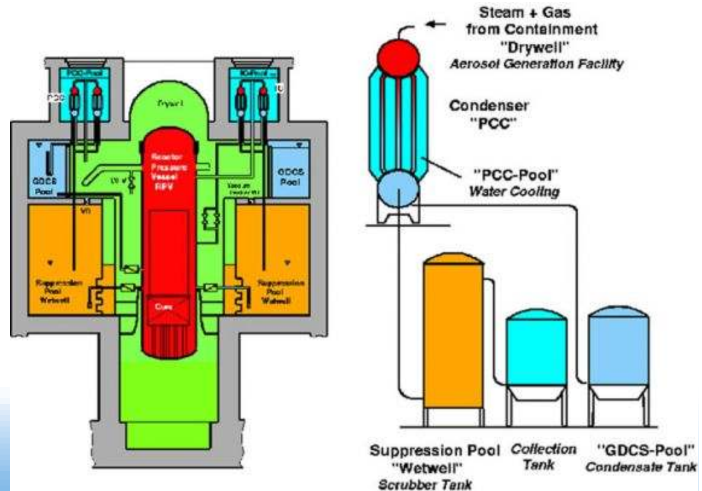
GE Hitachi ESBWR Features

Natural circulation boiling water reactor with passive safety features

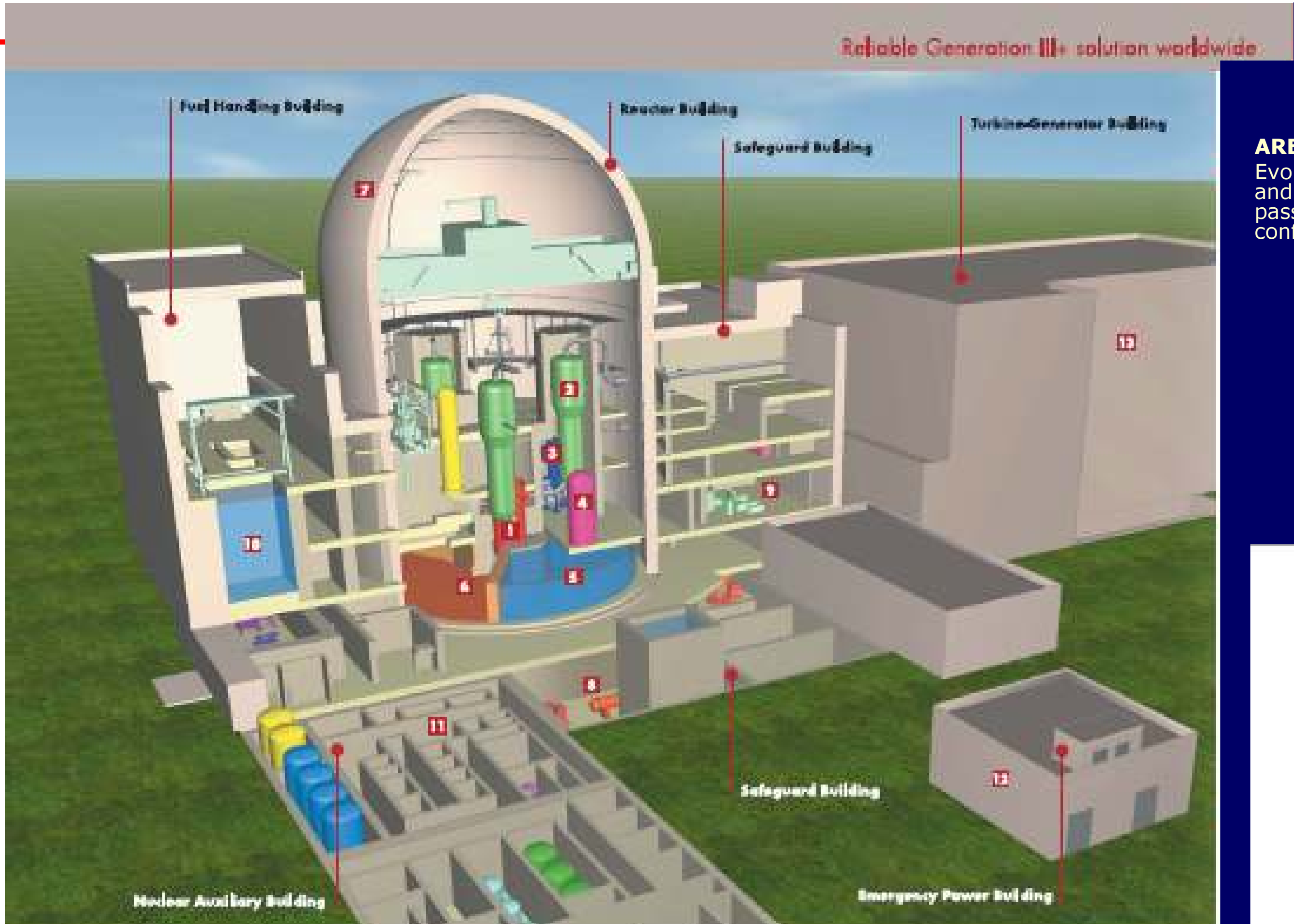
Electrical Power: 1,550 MWe
Thermal Output: 4,500 MWt
Plant Life: 60 Years
Fuel Enrichment: 4.2%
Plant Efficiency: 36.6%
Operation Cycle: 18-24 months
Plant Availability: 87%







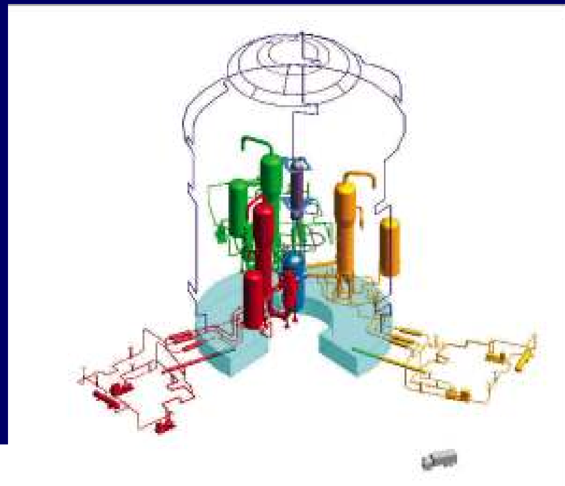
ATMEA1



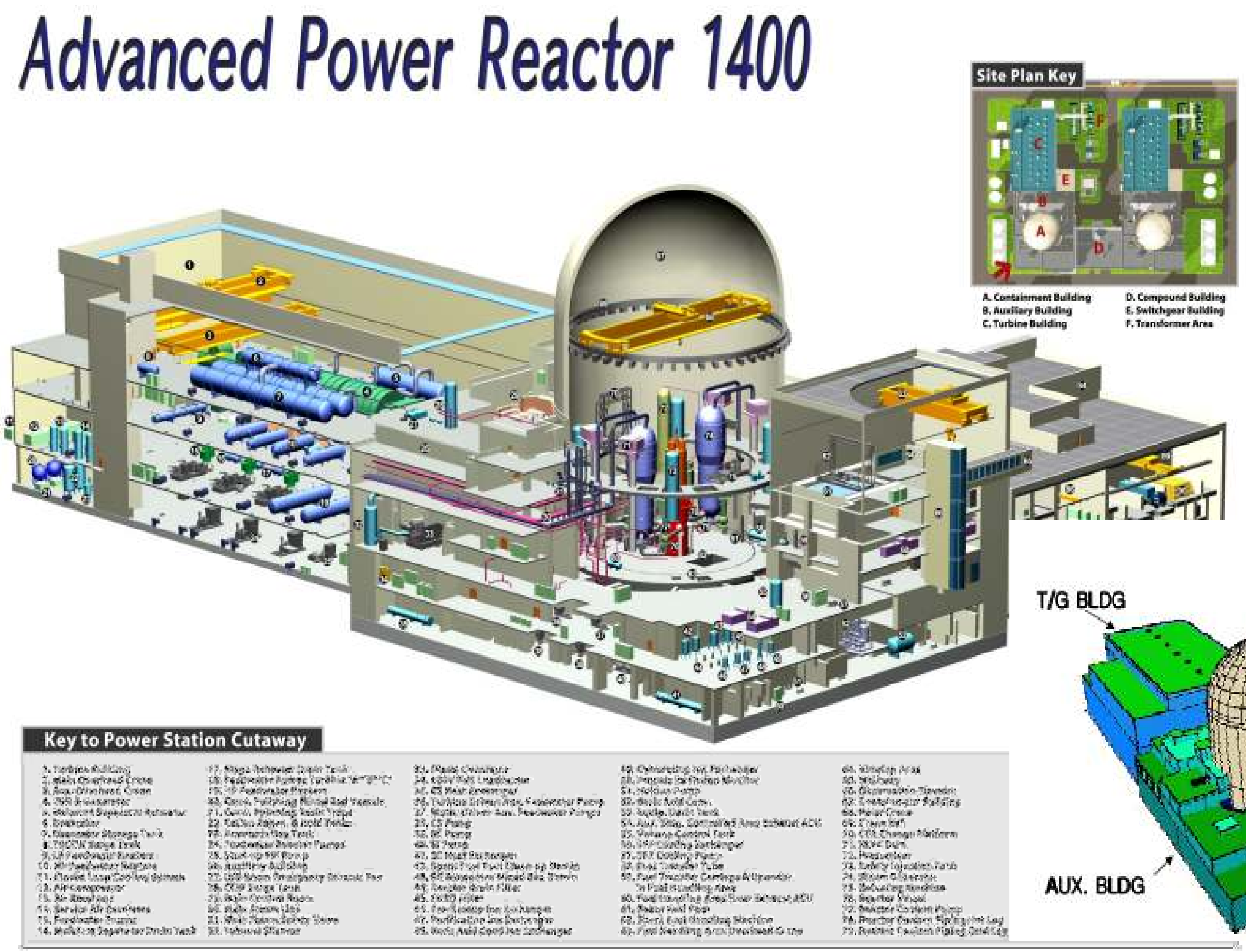
AREVA/MHI ATMEA1 FEATURES

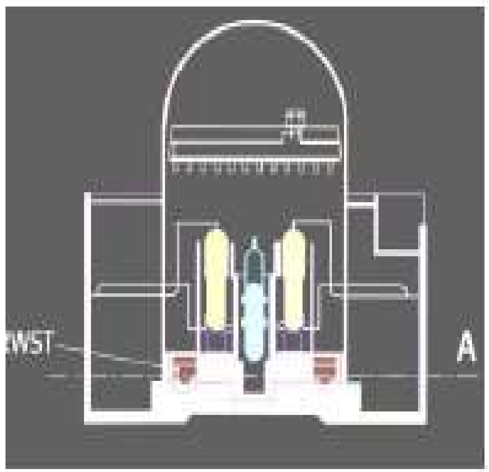
Evolutionary Generation III+ reactor, simple and improved PWR, taking advantage of both passive and active safety systems (3 loop configuration, 100% x 3 train safety system)

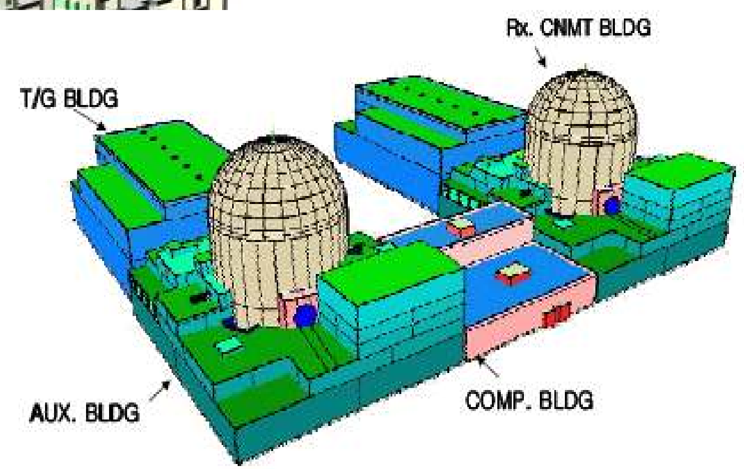
Electrical Power :	**1,000-1,150 MWe**
Thermal Output:	**2,860 – 3,150 MWt**
Plant Life:	**60 Years**
Plant Efficiency: (net)	**37%**
Operation Cycle:	**12 to 24 months**



APR1400


Advanced Power Reactor 1400
Site Plan Key
A. Containment Building
B. Auxiliary Building
C. Turbine Building
D. Compound Building
E. Switchgear Building
F. Transformer Area
Key to Power Station Cutaway


IWST
A


Rx. CNMT BLDG
T/G BLDG
AUX. BLDG
COMP. BLDG

SAFETY ASSESSMENT FOR FACILITIES AND ACTIVITIES (GS-R-4)
Selected Requirements

- Assessment of the possible radiation risks (Requirement 6)
- Assessment of human factors (Requirement 11)
- Scope of the s)
- Deterministic equirement 15)

SAFETY ASSESSMENT FOR FACILITIES AND ACTIVITIES (GS-R-4)

SELECTED REQUIREMENTS vs. GENERIC REACTOR SAFETY REVIEWS

- **Assessment of the possible radiation risks (Requirement 6)**
  - **The possible radiation risks associated with the facility or activity shall be identified and assessed**

4.19. This includes the level and likelihood of radiation exposure of workers and the public and the possible release of radioactive material to the environment that are associated with anticipated operational occurrences or accidents that lead to a loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source or any other source of radiation.

SAFETY ASSESSMENT FOR FACILITIES AND ACTIVITIES (GS-R-4)

SELECTED REQUIREMENTS vs. GENERIC REACTOR SAFETY REVIEWS

- **Findings**
  - Absence or limited scope of Level 2 PSA (or even Level 1 PSA)
  - Omission of certain initiating events (usually accidents at shutdown operational modes or accidents in radwaste treatment systems or spent fuel management systems)
  - Missing justification for categorization of initiating events
  - Missing data important for evaluation of radiological status prior the accident (cladding defects, excessive coolant radioactivity, and leaking steam generator tubes)
  - Assumptions used in safety analysis not presented in a clear and convincing way
  - Inconsistencies in transfer of data (without sufficient justification) from thermal-hydraulic analysis to containment analysis and to source term analysis
  - Unexpected rapid increase of doses in the environment with decreasing probability of occurrence in the range 1E-6 – 1.E-7/r.year (increase more than 2 orders of magnitude)
  - Over- conservatism used in analysis of design basis accidents (e.g. postulation of a core melt) leading to the conclusion that radiological consequences of design basis accidents are more severe than of severe accidents
  - Missing assessment of doses to control room staff in case of severe accidents

SAFETY ASSESSMENT FOR FACILITIES AND ACTIVITIES (GS-R-4)

SELECTED REQUIREMENTS vs. GENERIC REACTOR SAFETY REVIEWS

- **Assessment of human factors (Requirement 11)**

  - **Human interactions with the facility or activity shall be addressed in the safety assessment and it shall be determined whether the procedures and safety measures that are provided for all normal operational activities, in particular those that are necessary for implementation of the operational limits and conditions, and those that are required in response to anticipated operational occurrences and accidents, ensure an adequate level of safety**

  4.40. It has to be determined in the safety assessment whether requirements relating to human factors were addressed in the design and operation of a facility or in the way in which an activity is conducted. This includes those human factors relating to ergonomic design in all areas and to human–machine interfaces where activities are carried out..

SAFETY ASSESSMENT FOR FACILITIES AND ACTIVITIES (GS-R-4)

SELECTED REQUIREMENTS vs. GENERIC REACTOR SAFETY REVIEWS

- **Findings**

  - **PSA and Human Reliability Analysis (HRA) results are not used in developing the emergency procedures**

  - **The time windows for several operator actions are not supported by thermal hydraulic calculations**

  - **The thermal hydraulic analyses supporting the calculation of time windows for operator actions do not address all features of the accident sequences.**

SAFETY ASSESSMENT FOR FACILITIES AND ACTIVITIES (GS-R-4)

SELECTED REQUIREMENTS vs. GENERIC REACTOR SAFETY REVIEWS

- **Scope of the safety analysis (Requirement 14)**
  - **The performance of a facility or activity in all operational states and, as necessary, in the post-operational phase shall be assessed in the safety analysis.**

    4.50 The safety analysis has to address both the consequences arising from all normal operational conditions (including start-up and shutdown where appropriate) and the frequencies and consequences associated with all anticipated operational occurrences and accident conditions shall be addressed in the safety analysis. This includes accidents that have been taken into account in the design (referred to as design basis accidents) and beyond design basis accidents (including severe accidents) for facilities and activities where the radiation risks are high. The analysis has to be performed to a scope and level of detail that corresponds to the magnitude of the radiation risks associated with the facility or activity, the frequency of the events included in the analysis, the complexity of the facility or activity, and the uncertainties inherent in the processes that are included in the analysis.

SAFETY ASSESSMENT FOR FACILITIES AND ACTIVITIES (GS-R-4)

SELECTED REQUIREMENTS vs. GENERIC REACTOR SAFETY REVIEWS

- **Findings**
  - No separate analysis of a category of BDBA without severe core damage
  - No concise description of which global or detailed acceptance criteria have been used, including criteria associated with high burn-up issues.
  - Missing full power Level 2 PSA
  - Limited scope LPSD PSA
  - Missing analysis of events related to accidents related to the spent fuel pool
  - Inconsistencies in targets for severe accidents

SAFETY ASSESSMENT FOR FACILITIES AND ACTIVITIES (GS-R-4)

SELECTED REQUIREMENTS vs. GENERIC REACTOR SAFETY REVIEWS

- **Deterministic and probabilistic approaches (Requirement 15)**
  - **Both deterministic and probabilistic approaches shall be included in the safety analysis.**

4.55. The objectives of a probabilistic safety analysis are shall be to determine all the significant contributing factors to the radiation risks arising from a facility or activity, and to evaluate the extent to which the overall design is well balanced and meets probabilistic safety criteria where these have been defined. In the area of reactor safety, probabilistic safety analysis uses a comprehensive, structured approach to identify failure scenarios. It constitutes a conceptual and mathematical tool for deriving numerical estimates of risk. The probabilistic approach uses realistic assumptions whenever possible and provides a framework for addressing many of the uncertainties explicitly. Probabilistic approaches may provide insights into system performance, reliability, interactions and weaknesses in the design, the application of defence in depth and risks that it may not be possible to derive from a deterministic analysis.

SAFETY ASSESSMENT FOR FACILITIES AND ACTIVITIES (GS-R-4)

SELECTED REQUIREMENTS vs. GENERIC REACTOR SAFETY REVIEWS

- **Findings**
  - Missing full power Level 2 PSA, limited scope of Low Power and Shutdown PSA
  - Use of old data sources, no evidence of analysing recent (national or international) operating experience (PIEs, failure rates)
  - Missing or insufficient uncertainty & sensitivity studies, no display of uncertainty bands
  - Insufficient documentation of phenomenological aspects
  - Unusually low Core Damage Frequency or Large Release Frequency results
  - Missing definition of core damage
  - Cliff-edge effects (releases)
  - Unusually large contributions from individual accident sequences
  - Inconsistencies between tables reporting results
  - Insufficient documentation of application of THERP methodology
  - Insufficient documentation of reliability data used
  - Missing information on truncation criteria used
  - Insufficient information about extrapolation of results from smaller to larger size reactors
  - Need for review of fire PSA

CONCLUDING REMARKS (1/2)

- **Safety assessment is a key element of a safe and economic nuclear power programme:**

  - **By its nature, a nuclear power programme involves issues and challenges associated with nuclear material, radiation and related challenges**

  - **A nuclear power programme is a major undertaking requiring careful planning, preparation and investment in a sustainable infrastructure that provides legal, regulatory, technological, human and industrial support to ensure that the nuclear material is used exclusively for peaceful purposes and in a safe and secure manner**

CONCLUDING REMARKS 2/2

- **Safety assessment is building confidence**

  - **Confidence that the tools and processes used to design and assess the safety are the right tools, that they are verified and validated for intended use**

  - **Confidence that the plant will operate as designed and that it will respond as designed to accident conditions**

International Atomic Energy Agency

…Thank you for your attention