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2152-6

Joint ICTP-IAEA Course on Natural Circulation Phenomena and Passive Safety Systems in Advanced Water Cooled Reactors

17 - 21 May 2010

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IAEA Training Course on Natural Circulation in Water-Cooled Nuclear Power Plants,
International Centre of Theoretical Physics (ICTP), Trieste, Italy
17th to 21st May, 2010, Paper ID. T22

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KEY WORDS

Safety requirements, advanced nuclear reactors, European utility requirements, Generation IV requirements.

ABSTRACT

In this paper, overview on some aspects of European Utility Requirements (EUR) and also for Generation IV initiative with the technology goals will be provided.

The major objectives of the EUR document have been to develop requirements addressed to the LWR plant designers and vendors. It is a tool for promoting the harmonization of the most important plant features that were often too country specific.

Generation IV is a new generation of nuclear energy systems that can be made available to the market by 2030 or earlier, and that offers significant advances toward challenging technological goals. These goals are defined in the broad areas of sustainability, safety and reliability, and economics.

Use of EUR and Generation IV technology goals for safety aspects of future reactor designs is also discussed.

LECTURE OBJECTIVES

Lecture on this subject will provide overview both on the European Utility Requirements for safety aspects and Generation IV Technology Goals in the safety area.

1. INTRODUCTION

The major European utilities decide to take a lead role in defining the main features of future plants and they initiated the development of a common requirements document, the European Utility

Requirements (EUR). They agreed to propose a common set of safety requirements in an effort to harmonize the safety requirements between the different European countries. The EUR scope was to allow development of competitive, standardized designs that would match the conditions in Europe and be licensable in the respective countries. The utilities provided their practical experience in the preparation of the EUR document.

In the mean time with the turn of the millennium, the importance of nuclear energy as vital and strategic resource in the U.S. and world's energy supply mix has also led to an initiative, termed Generation IV by the U.S. Department of Energy (DOE), to develop and demonstrate new and improved reactor technologies. As a result of this initiative, Generation IV technology goals are set and defined.

The following sections provide overview both for European Utility Requirements and also for Generation IV initiative with the technology goals (sections 2 and 5, respectively). Section 3 presents in some detail some of the safety aspects of the EUR, including system and containment safety, and accident prevention. Use of the EUR and Generation IV technological goals for safety aspects of the advanced and future nuclear reactor designs are discussed in sections 4 and 6, respectively. The concluding remarks are presented in section 7.

2. A SHORT OVERVIEW ON EUROPEAN UTILITY REQUIREMENTS

The major European electricity producers have worked on a common requirement document for future LWR plants since 1992 to get specifications acceptable together by the owners, the public and the safety authorities. Thus the designers can develop standard LWR designs that could be acceptable across Europe and the utilities can open their consultations to vendors on a common basis. Public and regulatory authorities should be improved as well. The EUR promoters are a group of organizations that represent the major Western Europe electricity producers committed to keeping the nuclear option open in Europe. Started with five partners in 1992, the group now includes 10 utility organizations.

The major objectives of the EUR document have been to develop requirements addressed to the LWR plant designers and vendors. It is a tool for promoting the harmonization of the most important plant features that were often too country specific. The main items considered in this convergence process are the safety approaches, targets, criteria and assessment methods, the standardized environmental design conditions and design methods, the performance targets, the design features of the main systems and equipment, and –at a lower level- the equipment specifications and standards. In the process of putting together the EUR document.

Significant benefits are expected in two fields:

- Better competitiveness vs. alternate electricity generation means
- Improved public and authorities' acceptance, thus allowing an easier licensability of a design developed following the EUR

The major objectives of the EUR organization are derived from these targets. These objectives are the foundation of the requirements developed in the EUR document: giving the producers means for controlling construction costs through standardization, signification, series ordering and consideration of maintenance at design stage. It also provides establishing a common specification valid in an area large enough so as to allow vendors to develop standard designs; establishing stable market conditions for a broader competition between suppliers; making sure that acceptable operation and fuel cycle costs can be achieved, even in an upset economic environment; prescribing ambitious – but achievable – availability and lifetime targets; harmonizing safety related requirements: common safety targets, common safety approaches and common technical solutions to safety problems; setting "good neighbour" requirements like low impact on the environment, reduction of emergency planning, consideration of decommissioning at the design stage, etc… On these bases, the main vendors are developing a number of standard designs that could be built in many countries with minimum adaptation, that show acceptable economic prospects and that actually meet the needs of the customer, including safety and licensing aspects.

EUR document is structured in 4 volumes [1], [2], and [3]. The whole document includes about forty chapters that deal with all topics a utility has to address to have a nuclear power plant developed and built.

- **Volume 1 Main policies and top tier requirements:** It is guidance on the safety policies and it defines the major design objectives that are implemented in the EUR document.
- **Volume 2 Generic nuclear island detailed requirements:** It contains all the generic requirements and preferences of the EUR utilities for the nuclear islands. It deals with matters applicable for all designs such as size, performance, safety approach and objectives, grid requirements, fuel cycle, component technology and functional requirements for systems. It also specifies the methodology to be used for safety and performance evaluation, and outline the information required by the utilities to carry out their own cost and performance assessment.
- **Volume 3 Design specific nuclear island requirements:** It contains a subset specific to each nuclear power plant design of interest to the participating utilities. Part 1 of this subset includes a plant description, Part 2 presents the results of the conformance assessment of the design versus the generic EUR requirements of Volume 2 and Part 3 contains the specific requirements, if any, that have been placed by EUR for the particular design. As of present five subsets have been released that are dedicated to BWR 90, EPR, EPP, ABWR and SWR 1000.
- **Volume 4 Power generation plant requirements:** It contains the generic detailed requirements for the Balance of Plant.

Altogether the EUR has some 150 requirements in Volume 1, 5,000 requirements in Volume 2 and 500 requirements in Volume 4. It is to be noted that the EUR promoters keep the final content of the document under close control and provide the contents of the different volumes in confidence and for limited use through the utilities, which are involved in the development of the EUR. Volumes 1, 2 and 4 have gone through number of revisions (presently, Volumes 1 and 2 have revision C, and Volume 4 has revision B and revision C is expected to be published [3]).

3. SOME OF THE EUR FOR SAFETY ASPECTS

Since the contents of the different volumes of the EUR was provided in confidence [2], only some of the requirements which are in open literature, e.g., [4] will be dealt in general terms. Additional chapters of EUR (e.g. 2.2, 2.4, 2.8, and 2.9) are necessary to carry out specific application and compliance assessment. Some of these EUR safety requirements are:

- Application of "As low as reasonably achievable (ALARA)" principle;
- Forgiving design characterized by simplicity and passive safety features where appropriate;
- Safety classification based on: Design Basis Condition (DBC) and Design Extension Conditions (DEC);
- Redundancy and independence of safety systems performing DBC and some DEC functions to ensure prevention of common cause failure;

- For DBC's reaching a safe shutdown state within 24 hours from the accident initiation and in any case within 72 hours. For DEC a safe shutdown state should be reached within one week as a goal and before 30 days in any case; the confinement of fission products and protection against external events in normal operation, DBC and DEC's. The containment should not experience early failure under DEC conditions;
- The containment design has to exclude hydrogen detonation;
- If in-vessel coolability can not be demonstrated, then ex-vessel coolability and non-criticality features must be provided;
- The leakage rate from the containment should not exceed 0.5-1.0 V%/day for a pre-stressed concrete shell without a liner, 0.1-0.5 V%/day with a liner or for a metal shell;
- On-line monitoring of containment leak-tightness during operation;
- The containment should not remain at elevated pressure after the accident. The pressure should be reduced at least to 50% of its peak value in the worst DBC;
- Requirement for a secondary containment, for example by a partial solution of enclosing all penetrations;
- Secondary bypass leakage should not exceed 10% of the primary containment leakage;
- Next generation of NPPs will be safer by increasing design robustness, better operation and maintenance (preventive means) rather than through protective actions;
- If possible, public evacuation planning should not be necessary;
- For accident prevention- simplification of the safety systems, elimination of common mode failures by physical separation and diverse back-up systems, less sensitivity to human errors by designing components with larger inventories of water, optimized man-machine interface by digital instrumentation and control systems, use of probabilistic risk assessment to limit the residual risk due to total loss of safety grade systems.

These safety requirements for the system, EUR requirements for the containment and EUR top tier requirements including plant characteristics, operational targets, standardization, economic objectives, core damage prevention and mitigation, and release rates are itemized and given in tables 1 to 3.

4. USE OF EUR FOR SAFETY ASPECTS OF FUTURE NUCLEAR REACTOR DESIGNS

The EUR promoters are producing evaluations of selected LWR designs and they include the results of these applications in Vol. 3 of the EUR document. Six such subsets have been published between 1997 and 2007. Presently, six subsets dedicated to the ABWR, BWR90, EPR, EPP, SWR1000 and AES92 (VVER 1000) projects have been published [3]. The requirements have also been employed for the design of the ESBWR and AP1000 application is ready to be published. Consequently, the EUR is being applied for the design of number of reactor systems. In addition, use of EUR has been also seen in the framework of calling bids, e.g., Olkiluoto-3 (Finland), Belene (Bulgarian), etc.

All these EUR safety requirements have also been considered and taken into account during the evaluation of the merit and feasibility of the HPLWR concept and the results are provided in table form for the primary system and the containment system in reference [5] and the general conclusions drawn are included in [6].

During applying the EUR to different types of reactor designs, the analyses of compliance, which is detailed process and application, have been carried to the elementary level. This process have requested and needed much resources and time both by the EUR utilities and by the interested vendors. These detailed assessments of compliance to EUR have resulted in a kind of qualification of the volumes 1 and 2 against actual reactor design projects.

It is to be noted that the EUR document is a reference user's document for LWR plants to be built in Europe beyond the turn of the century, but it is not a document for licensing the plants. The plant designs will always need to duly comply with the national licensing regulations and laws.

5. A SHORT OVERVIEW ON THE GENERATION IV INITIATIVE

The Generation IV project was initiated by the United States Department of Energy's (USDOE's) Office of Nuclear Energy, Science and Technology. Concerns over energy resource availability, climate change, air quality, and energy security suggest an important role for nuclear power in future energy supplies. While the current Generation II and III nuclear power plant designs provide an economically, technically, and publicly acceptable electricity supply in many markets, further advances in nuclear energy system design can broaden the opportunities for the use of nuclear energy. To explore these opportunities USDOE has engaged governments, industry, and the research community worldwide in a wide-ranging discussion on the development of next-generation nuclear energy systems known as "Generation IV". This has also resulted in the formation of the Generation IV International Forum (GIF), a group whose member countries are interested in jointly defining the future of nuclear energy research and development. The Generation IV project will be guided by a technology roadmap that will identify research and development pathways for the most promising technologies. The development of a technology roadmap is completed by the end of 2002.

Generation IV is a new generation of nuclear energy systems that can be made available to the market by 2030 or earlier, and that offers significant advances toward challenging goals. These goals are defined in the broad areas of sustainability, safety and reliability, and economics [7]. Sustainability goals focus on fuel utilization, waste management, and proliferation resistance. Safety and reliability goals focus on safe and reliable operation, investment protection, and essentially eliminating the need for emergency response. Economics goals focus on competitive life cycle and energy production costs and financial risk.

5.1 Generation IV Technology Goals

The goals have three purposes: First, they define and guide the development and design of Generation IV systems. Second, they are challenging and will stimulate the search for innovative nuclear energy systems—both fuel cycles and reactor technologies. Third, they serve as the basis for developing criteria to assess and compare the systems in a technology roadmap. Eight goals [7] for Generation IV nuclear energy systems are proposed in three areas: sustainability, safety and reliability, and economics. The goals are arranged to facilitate the flow of information rather than to recommend an order of importance. Each goal is stated concisely. Supporting each goal is a discussion that clarifies the intent of the specific wording and the background from which it evolved. The discussion cites illustrative examples and suggests potential approaches. It is not meant to direct or constrain creativity and innovation. Also, much of the discussion is purposely drawn from worldwide experience that is useful in guiding the development of goals.

- A set of guiding principles is used to derive the Generation IV technology goals:
- Technology goals for Generation IV systems must be challenging and stimulate innovation.
- Generation IV systems must be responsive to energy needs worldwide.
- Generation IV concepts must define complete nuclear energy systems, not simply reactor technologies.

- All candidates should be evaluated against the goals on the basis of their benefits, costs, risks, and uncertainties, with no technologies excluded at the outset.
- Since, the Generation IV technology goals are intended to stretch the envelope of current technologies, some word of caution for clarification need to be noted:
- The goals will guide the development of new nuclear energy systems. The objective of Generation IV systems is to meet as many goals as possible.
- The goals are not overly specific because the social, regulatory, economic, and technological conditions of 2030 and beyond are uncertain.

The goals must not be construed as regulatory requirements. Eight goals for Generation IV nuclear systems are:

Sustainability–1. Generation IV nuclear energy systems including fuel cycles will provide sustainable energy generation that meets clean air objectives and promotes long-term availability of systems and effective fuel utilization for worldwide energy production.

Sustainability–2. Generation IV nuclear energy systems will minimize and manage their nuclear waste and notably reduce the long term stewardship burden in the future, thereby improving protection for the public health and the environment.

Sustainability–3. Generation IV nuclear energy systems including fuel cycles will increase the assurance that they are a very unattractive and least desirable route for diversion or theft of weapons-usable materials.

Safety and Reliability –1. Generation IV nuclear energy systems operations will excel in safety and reliability.

Safety and Reliability–2. Generation IV nuclear energy systems will have a very low likelihood and degree of reactor core damage.

Safety and Reliability–3. Generation IV nuclear energy systems will eliminate the need for offsite emergency response.

Economics–1. Generation IV nuclear energy systems will have a clear life cycle cost advantage over other energy sources.

Economics–2. Generation IV nuclear energy systems will have a level of financial risk comparable to other energy projects.

The detailed discussion of each goal is given in [7]. Only, the safety and reliability related aspects of the Generation IV technological goals are specifically provided in tables 4 to 5.

6. USE OF GENERATION IV TECHNOLOGY GOALS FOR SAFETY ASPECTS OF FUTURE NUCLEAR REACTOR DESIGNS

The GIF discussed the R&D necessary to support next-generation nuclear energy systems, from its beginning (January 2000). From those discussions a technology roadmap to guide the Generation IV effort began and was completed in two years with the participation of over 100 experts from the GIF countries. The effort ended in December 2002 with issue of the final Generation IV Technology Roadmap [8]. This Roadmap evaluated over 100 future systems proposed by researchers around the world.

The roadmap identified six most promising systems. Two employ a thermal neutron spectrum with coolants and temperatures that enable electricity production with high efficiency: The

Supercritical Water Reactor (SCWR), and the Very High temperature Reactor (VHTR). Three employ a fast neutron spectrum to enable more effective management of nuclear materials through recycling of most components in the discharged fuel: The Gas-cooled Fast Reactor (GFR), the Lead-cooled Fast Reactor (LFR), and the Sodium-cooled Fast Reactor (SFR). The last one, the Molten Salt Reactor (MSR) employs a circulating liquid fuel mixture that offers considerable flexibility for recycling nuclear materials.

During the R&D phases of above mentioned reactor system designs, it is necessary to review the application of Generation IV Technology Goals at different stages of the development such that for the final design of the future reactor systems these goals are fulfilled and satisfied. As an example this process has already been applied to conceptual HPLWR design (it is European version of SCWR) and the results are for the preliminary design stage are reported in the literature [5] and [6]. Since many aspects of conceptual HPLWR design are not known in detail until the completion of the basic design and the related R&D efforts, the Generation IV technology goals in the safety and reliability area are applied to HPLWR design in general. This comparison indicates that the present preliminary design of the HPLWR has the potential to meet most of these goals.

7. CONCLUDING REMARKS

The European Utility Requirements (EUR), which are currently considered to be most advanced and most complete in Europe, have been applied in the design of advanced LWRs such as the EPR and the SWR 1000 (detailed designs of which are very advanced). As a general guide, the EUR can also be taken as basis for design of the future reactor systems. Additionally, the trends of future requirements, as expressed in the requirements known from the Generation IV initiative, can also be considered in order to include further advanced ideas.

It is also to be noted that, in general, the Generation IV requirements are generally compatible with the top tier EUR document [1], [2], and [3]. This is an important observation, since by using the EUR as a guide for the detailed design of the future reactor systems; it will also insure the conformity of these designs with Generation IV goals.

NOMENCLATURE

ABWR	Advanced Boiling Water Reactor
ALWR	Advanced Light Water Reactors
ADS	Automatic Depressurization System
ALARA	As Low As Reasonably Achievable
BWR	Boiling Water Reactor
DBC	Design Basis Condition
DEC	Design Extension Condition
EPP	European Passive Plant
EPR	European Pressurized Water Reactor
ESBWR	European Simplified BWR
EUR	European Utility Requirements
GIF	Generation IV International Forum
HP	High Pressure
HPLWR	High Performance Light Water Reactor
I&C	Instrumentation and Control
LOCA	Loss Of Coolant Accident
LP	Low Pressure
LPCI	Low Pressure Coolant Injection
R&D	Research and Development

SWR	Siede Wasser Reactor (Framatome ANP, Passive design BWR)

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Table 1- Some EUR Safety Requirements

Some EUR Safety Requirements		
1.1	Application of "As Low As Reasonably Achievable (ALARA)" Principle	
1.2	Design to be forgiving and characterized by simplicity and transparency with the use, where appropriate, of passive safety features	
1.3	Safety classification based on: design basis conditions (DBC) and design extension conditions (DEC).	
1.4	Safety systems performing DBC functions and certain DEC functions are required to have a degree of redundancy, diversity (e.g. passive versus active), independence, functional isolation and segregation to ensure prevention from common cause failure	
1.5	Design shall ensure autonomy that for DBC's and Complex Sequences, a Safe Shutdown State can be reached, as a goal within 24 hours from accident start and anyway within 72 hours. For DEC a safe Shutdown State should be reached within 1 week as a goal and before 30 days anyway.	
1.6	EUR requires in addition the consideration of other engineering criteria, such prevention of Common Cause failures, diversity, independence and segregation	
1.7	External hazards like earthquake, extreme weather, floods, aircraft crash, adjace installations, electromagnetic interference, sabotage and internal hazards like fir noxious substances, failure of pressure parts, disruption of rotary equipmer dropped loads and electromagnetic interference must be addressed	
1.8	Requirements on the systems are set in terms of operational performance to ensu the reactivity control, heat removal and radioactivity confinement. Reactivi coefficients acceptable values, stable operation and reliability of the shutdov systems are all EUR requirements	
1.9	For the core heat removal, temperature, pressure, flow and inventory control a required besides depressurization capability and pressure boundary integrity. F the latter, the use of the Leak Before Break (LBB) methodology is foreseen	
1.10	In the very long term after an accident, provisions for the connection of mobi equipment are required	
1.11	Important provisions required by EUR to demonstrate the in vessel corium cooli and avoidance of base mat perforation by the use of automatic depressurizati system and the core spreading area that allows for solidification of the crust	
1.12	Under DEC's, not a classical environmental qualification is required, rather th equipment survival has to be demostrated	

Table 2- EUR Requirements for the Containment System

EUR Requirements on the Containment System		
2.1	Aim mainly at strengthening the confinement of the fission products and protection against external events. The containment shall perform these functions in normal operation (including shutdown), DBC and DEC's	
2.2	Under DEC's conditions early failure of the Containment system has to be ruled out b design (e.g. for PWR's adoption of a full primary circuit depressurization system). vessel core debris interaction with water (steam explosion), high pressure ejection molten core leading to direct containment heating; ex-vessel debris interaction with wat (subcooled water, steam explosion) and reactivity accidents (including heterogeneou boron dilution) have all to be prevented by design	
2.3	The design of the Containment system has to exclude hydrogen concentrations that ca lead to detonation. As a consequence the effectiveness of a hydrogen recombinatio system must be demonstrated. As an alternative inertization is required. The effect other flammable gases e.g., CO must be accounted for	
2.4	If in-vessel coolability cannot be demonstrated ex-vessel coolability and non-criticali features must be provided. A core catcher or corium spreading room must be provided drive the corium into a stable situation	
2.5	For the design of the Containment shell, particular attention has to be given in requirin that also severe accidents be taken into account, even if not necessarily direct determining the Containment design pressure. The Designer must demonstrate that, case the pressure and temperature exceed the design values, the assumed leak rate adequately supported. Also the local effects of hydrogen deflagration and sustaine flames have to be considered	
2.6	Credible Primary Containment leak rate values are provided by EUR: for a pre-stresse concrete shell without liner 0.5 to 1.0 V%/d; for a pre-stressed concrete with liner 0.1 0.5 V%/d; for a metal shell 0.1 to 0.5 V%/d	
2.7	Means should be provided to ensure on-line monitoring of Containment leak-tightnes during operation	
2.8	Containment should not remain at elevated pressure for a long time after the accident. In 24 hours the pressure has to be reduced at least to 50% of its peak value in the worst DBC	
2.9	In addition to the Primary Containment, the EUR requires also a Secondary Containmen Secondary Containment function can be demonstrated to meet also in the case that th Secondary Containment is not kept under a negative pressure, provided that the lea tightness is ensured. For the secondary containment a "partial" solution enclosing all th penetrations is acceptable.	
2.10	The Secondary bypass leakage is required not to exceed 10% of the Prima Containment leakage	
2.11	Through the combination of the different lines of defense the EUR Requirements aim achieving a degree of protection of the population and the environment higher than th one achieved by previous generation of NPP and by the majority of other industri hazards. This high degree of protection is aimed to be reached with very limited or n external mitigation. In the next generation of NPPs an improvement in safety will b reached through increasing the role of design robustness, better operation an maintenance (preventive means) rather than through protective actions.	
2.12	Public evacuation planning should not be necessary. Eventually nuclear emergency situations should be managed with those protective measures normally planned in the industrialized countries for generic public protection	

Table 3 - EUR Top Tier Requirements

European Utility Requirements (EUR)		
	1. Plant Characteristics	
1.1	Maximum burnup 60 GWd/t for UO_2, 45GWd/t for MOX	
1.2	Refueling interval 12 to 24 months	
1.3	Design life 60 years	
1.4	Digital I&C technology	
1.5	Optimized role of operator	t
1.6	High degree of automation for rapid, complex or frequently repeated actions	
1.7	Redundant operator workstaions for main control room	
1.8	Diversified safety- classified actuators	
1.9	Extended autonomy with regard to operator actions (30 minutes) and water and power supply (24/72 hours)	
	2. Operational Targets	
2.1	Plant availability greater than 87%	
2.2	Refueling and maintenance outage less than 25 days	
2.3	Refueling possible in less than 17 days	
2.4	Major 10 years outage less than 180 days	
2.5	Less than 1 unplanned scram per year	
2.6	Unplanned outage less than 5 days/year	
2.7	Specified maneuvering capabilities, e.g. 24 hours starting time from cold shutdown to full load; scheduled/unscheduled load variations- between 20% and 50% rated power: 2.5%/min; between 50% and 100% rated power: 5%/min	
2.8	Capability to withstand specified network faults	
	3. Standardization	
3.1	Standard earthquake design acceleration level 0.25 g	
3.2	Seismic margin assessment for items critical for safety	
3.3	External explosion wave (100 mbar, 300 ms)	
3.4	Probabilistic approach for military aircraft crash, unless deterministic approach is required by authorities	
	4. Economic Objectives	
4.1	Competitive with coal fired or combined cycle plants (15% cheaper at base load operation, same generation costs at 4500 to 5500 full power hours/year) including capital, operation + maintenance, fuel cycle and decommissioning costs	
4.2	Overnight capital costs of 1100 ECU/KW (1995 value)	
4.2	60 months from first concrete to commercial operation	

	5. Core damage prevention	
5.1	Core damage cumulative frequency less than 10^{-5} per year, considering both operation and shutdown states and including internal and external events	
	6. Mitigation	
6.1	Cumulative frequency of exceeding the limiting release set for severe accident with core degradation shall be shown by a PSA to be less than 10^{-6} per reactor year	
6.2	Hydrogen control such that the H_2 concentration in the containment will be less than 10% under dry conditions and considering the amount of H_2 generated by 100% oxidation of the active fuel cladding	
6.3	Containment as a leak tight structure, and a secondary containment to collect any releases from the primary containment. Containment is designed for internal and external events and for severe accidents (including molten core materials)	
6.4	High pressure melt ejection during a severe accident is eliminated by RCS depressurization and the containment shall include measures to decrease pressure to 50% of peak value in 24 hours after the accident	
	7. Release rates	
7.1	Release rates take into account national and international requirements and should implement the ALARA concept. Release targets for severe accidents are Limiting Release. The EUR anticipate that these targets will imply: minimal emergency protection beyond 800 m from the reactor during early releases from the containment; No delayed action (temporary transfer of people) at any time beyond about 3 km from the reactor; No long term actions involving permanent (longer than 1 year) resettlement of the public, at any distance beyond 800 m from the reactor; Restrictions on the consumption of food and crops shall be limited in terms of time scale and ground area. Target releases for 1500 MWe LWR are: Liquid discharge: GBq/a, Noble gases TBq/a, Halogen and aerosols GBq/a.	
7.2	Target for low activity solid radwaste: Total volume of the final solid radwaste produced by one plant should be less than 50 m^3 per 1000 MWe per year of normal operation	

Table 3 (Continued)- EUR Top Tier Requirements

Table 4- Safety and Reliability –1:

Gen IV nuclear energy systems operations will excel in safety and reliability

Generation IV Safety and Reliability -1		
2.1.1	This goal aims at increasing operational safety by reducing: the number of events, equipment problems, human performance issues that can initiate accidents or cause them into more severe accident	
2.1.2	It also aims at achieving increased nuclear energy systems reliability that will benefi their economics. Appropriate requirements and robust designs are needed to advanc such operational objectives and to support the demonstration of safety that enhanc public confidence	
2.1.3	During the last two decades, operating nuclear power plants have improved their safety levels significantly. At the same time, design requirements have been developed t simplify their design, enhance their defence-in-depth in nuclear safety, and improve their constructability, operability, maintainability, and economics	
2.1.4	Increased emphasis is being put on preventing abnormal events and on improving human performance by using advanced instrumentation and digital systems	
2.1.5	Also, the demonstration of safety is being strengthened through prototype demonstration that is supported by validated analysis tools and testing, or by showing that the design relies on proven technology supported by ample analysis, testing, and research results	
2.1.6	Radiation protection is being maintained over the total system lifetime by operating within the applicable standards and regulations. The concept of keeping radiation exposure as low as reasonably achievable (ALARA) is being successfully employed to lower radiation exposure	
2.1.7	Gen IV nuclear energy systems must continue to promote the highest levels of safety and reliability by adopting established principles and best practices developed by the industry and regulators to enhance public confidence, and by employing future technological advances	
2.1.8	The continued and judicious pursuit of excellence in safety and reliability is important to improving economics	

Table 5- Safety and Reliability –2:

Gen IV nuclear energy systems will have a very low likelihood and degree of reactor core damage

Generation IV Safety and Reliability -2		
2.2.1	This goal is vital to achieve investment protection for the owner/operators and to preserve the plant's ability to return to power	
2.2.2	There has been a strong trend over the years to reduce the possibility of reactor core damage. Probabilistic Risk Assessment (PRA) identifies and helps prevent accident sequences that could result in core damage and off-site radiation releases and reduces the uncertainties associated with them. For example the US ALWR Utility Requirements Document requires the plant designer to demonstrate a core damage frequency of less than 10^{-5} per reactor year by PRA. This is a factor of about 10 lower in frequency by comparison to the previous generation of LWR energy systems	
2.2.3	Additional means, such as passive features to provide cooling of the fuel and reducing the need for uninterrupted electrical power, have been valuable factors in establishing this trend	
2.2.4	The evaluation of passive safety should be continued and passive safety features incorporated into Gen IV nuclear energy systems whenever appropriate	

Table 6- Safety and Reliability –3:
Gen IV nuclear energy systems will eliminate the need for off-site emergency response

Generation IV Safety and Reliability -3		
2.3.1	The intent of this goal is, through design and application of advanced technology, to eliminate the need for off-site emergency response. Although its demonstration may eventually prove to be unachievable, this goal is intended to simulate innovation, leading to the development of designs that could meet it	
2.3.2	The strategy is to identify severe accidents that lead to offsite radioactive releases, and to evaluate the effectiveness and impact on economics of design features that eliminate the need for offsite emergency response	
2.3.3	The need for offsite emergency response has been interpreted as a safety weakness by the public and specifically by people living near nuclear facilities	
2.3.4	Hence, for Gen IV systems a design effort focused on elimination of the need for offsite emergency response is warranted	
2.3.5	This effort is in addition to actions, which will be taken to reduce the likelihood and degree of core damage required by the previous goal	