SEISMIC ISOLATION OF GEN IV LEAD-COOLED REACTORS

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ABSTRACT

Nowadays, seismic isolation is widely used to protect not only civil buildings (over 10,000 all over the world [1]) but also bridges, viaducts and industrial plants, and is considered the most promising technology to protect nuclear reactors from violent earthquakes. In spite of this, only two nuclear plants are currently provided with base isolation: 4 PWRs at Cruas (France), and 2 PWRs at Koeberg (South Africa). In addition, the Jules Horowitz Reactor, now under construction at Cadarache (France), must be cited.

The extremely limited number of existing isolated nuclear reactors is probably due to the relatively low seismic input assumed as design for the Generation II reactors, and also because most of them were water reactors, which are characterized by quite stiff structures and rigid components. As a matter of fact, among the new designs of water reactors, only IRIS (International Reactor Innovative and Secure) and 4S (Super Safe, Small and Simple) are provided with base isolation. On the contrary, among the fast reactors, most of the recent designs already include seismic isolation: ALMR (Advanced Liquid Metal Reactor), S-PRISM (Power Reactor Innovative Small Module), DFBR (Demonstration Fast Breeder Reactor), DFBR (Demonstration Fast Breeder Reactor), STAR-LM (Secure Transportable Autonomous Reactor-Liquid Metal) and EFR (European Fast Breeder Reactor). Unfortunately, no application of these reactors has been done, yet, and there is a dramatic lack of information and experimental results about the behavior of large isolators under severe dynamic conditions.

As far as lead cooled reactors is concerned, the most recent designs do not include seismic isolation (with the exception of the “small” STAR-LM). However, such reactors, in addition to structural problems similar to those of the abovementioned sodium reactors, have to deal with the high density of the coolant, which induces sloshing effects and transmits higher inertial forces to the tank and pipelines.

The paper, after a short presentation of the world state-of-the-art of seismically isolated nuclear reactors (included new designs), focuses on the main problems encountered in the application of this technology to lead reactors, such as the need of manufacturing and testing very large isolators and to design interface components, and the lack of standards specifically addressed to isolated nuclear reactors.

INTRODUCTION

On September 21, 2007 the Sustainable Nuclear Energy Technology Platform (SNE-TP) was launched in Brussels, through which the European research nuclear fission community joined its efforts to issue a Strategic Research Agenda (SRA) for achieving sustainable nuclear fission energy. The main objective of the SRA is to provide decision makers as well as the scientific community with clearly identified technological road-maps for the development of fission technologies, being the nuclear energy considered as one of Europe’s main low carbon energy technologies.

The SRA of SNETP has been based, substantially, on the following ideas:

- Generation II and III Light Water Reactors (LWR) nuclear reactors contribute already very positively to the objectives in the EU's energy policy. Existing reactors have an outstanding safety track record and they offer inexpensive base-load electricity; uranium supply is secure. In addition, nuclear power plants emit very low lifecycle greenhouse gases.
- Innovative Generation IV fast reactor systems with a closed fuel cycle will offer greatly improved sustainability. They will produce 50 to 100 times more electricity than current reactors from the same amount of uranium enabling natural resources to last thousands of years. In addition, with advanced fuel cycles and the partitioning and transmutation (i.e. recycling) of minor actinides and long-lived fission products, they will produce significantly less waste for disposal (in terms of volume, thermal load and radio-active inventory) thereby further reducing environmental impacts.

- Other Generation IV reactors operating at very high temperature will provide low carbon process heat for the mass production of hydrogen and other industrial processes, including desalination, thereby addressing major challenges for the future, i.e. replacing oil or extending its exploitation and supplying arid regions with drinking water.

Looking at the area of the development of fast neutron systems, European stakeholders have chosen to concentrate their efforts along two directions:

- Sodium-cooled fast neutron reactor (SFR) is considered as a known and proven technology but for which innovations are necessary to fulfill the criteria of Generation IV reactors.
- In parallel, a coolant technology alternative to sodium, either lead or gas, will be selected between 2010 and 2012 to offer decision makers a choice of reactor systems and to limit technological risks. In this time-frame, the two systems will be compared in terms of potential, R&D needs and developmental timeline.

It is clear, therefore, that great efforts have to be put in identifying and addressing all the topics of major relevance for the demonstration of the abovementioned fast spectrum technologies in a short timeframe. In this context, a topic of particular relevance is certainly the one of safety and mitigation of risks. In general, in fact, it has to be noticed that to be sustainable energy production must avoid endangering the well-being of future generations, not only by reducing the use of natural resources but also by minimizing detrimental effects on public health and environment. This means that electricity production must achieve high levels of safety, both against internal and external damage events, and limit harmful emissions over the full lifecycle of the plant (cradle to grave).

In particular, for Generation IV reactors maintaining and enhancing the safe and reliable operation is an essential priority in the development. Generation IV reactors have to be highly secure and designed to withstand failure-driving events: their many protective features considerably reduce the impact of external or internal threats through the redundancy, diversity, and independence of the safety systems. This goal, strongly outlined in the Generation IV International Forum (GIF) roadmap, points out the need to increase public confidence in the security of nuclear energy facilities.

In this light, a huge effort have been dedicated, ever, to continuously increase the level of safety of Nuclear Power Plants against internally initiated events, reducing the associated core damage frequencies. This has, therefore, forced the nuclear engineering community to concentrate a significant research effort also on the evaluation and mitigation of risks associated to external events such as natural hazards (earthquakes, hurricanes, tornadoes, flooding, tsunamis and so forth) as well as other external risks, such as terroristic attack (i.e. aircraft or missile impacts). Note that there have been recently a large number of external events that have severely challenged structures and operations of nuclear plants: flooding in France and Finland, several big earthquakes (one of them struck Kashiwazaki-Kariwa, the largest nuclear power plant of the world), the 2004 Indian Ocean tsunami (which affected the Tamil Nadu reactor in India) and the more recent catastrophe in Japan, which severely damaged the Fukushima plant.

For the Lead Fast Reactor (LFR) and Accelerator Driven Systems (ADS) design, important R&D technology gaps are identified in the SNE-TP SRA as well as in the Generation IV Roadmap, in system design at level of seismic protection, in particular with respect to selected components as, e.g. core internals support and refueling machine design. The structural support of the reactor vessel, for example, containing dense Lead or Lead-Bismuth Eutectic (LBE) coolant, in fact, will require design development in seismic isolation approaches and sloshing suppression.

SEISMIC RISK IN LEAD-COOLED SYSTEMS

Safety concerns related to seismic events in lead-cooled systems

Main safety concerns related to immediate consequence of a seismic event in a heavy liquid metal reactor, therefore, are related to:

1. structural failures due to the dynamic loading,
2. core voiding by gas entrapped into primary coolant system,
3. functional failures of equipment due to coolant spill-out.

1) Dynamic loading on the elements of primary system in case of intensive seismic event can cause early core damage due to the following phenomena:

- *Loss of coolant from the primary system*. In most of contemporary pool-type designs loss of primary coolant is considered as very low probability because there is no piping below the coolant level and integrity of the vessel is considered as highly reliable. However, seismic events which can cause loss or leaks of primary coolant have to be considered seriously due to their consequences, even though the associated probability is very low.

- *Flow blockage in a fuel assembly*. Most likely outcome of the coolant flow blockage in a fuel assembly is overheating and eventual disintegration of the fuel. In a worst case scenario degradation of one fuel assembly may lead to propagation of core damage to the neighboring assemblies. Thus quantification of dynamic loading which may lead to a damage of an assembly in a seismic event is important element of safety assessment.
- *Steam generator tube rupture (in LFR pool design)*. Steam generator tube is highly loaded thin element of the system. There is a number of threats which originates from steam generator tube rupture (SGTR) or leakage (SGTL). In a nutshell, a SGTR event generates a pressure shock wave and discharges steam/water into a molten lead environment, bringing the fluid (lead) into motion and creating a potentially energetic situation that imposes a dynamic loading on the surrounding structure. There is also gradual pressurization of the vessel after SGTR due to inflow of the steam which also requires design of appropriate protection measures for isolation of ruptured tube and safe depressurization of the vessel.

2) Core voiding is one of the major threats which can lead to rapid reactivity insertion and consequent core disruptive accident in Lead cooled Fast Reactors. In compact pool designs the flow path to the core inlet is, in fact, rather short. Gas bubbles can be dragged down by the coolant flow to the inlet of the core and cause core voiding and transient overpower (TOP) accident. Gas bubbles can originate from:

- *sloshing* and violent breakup of coolant free surface,
- s*team leaking* from a ruptured steam generator tube (in a LFR pool design).

3) There are also risks related to malfunction of different elements of the primary system due to spill-out of the coolant during the seismic excitation. These threats are design specific and can affect such systems as gas-dam thermal insulators.

Considering the abovementioned critical risks related to earthquake events, then, seismic isolation represents a highly attractive strategy. For example, for the Lead-cooled fast reactor concepts, seismic isolation is explicitly regarded as a viability issue, as from the SNE-TP SRA.

Seismic isolation consists in the insertion, between the ground and the base of the structure, of suitable devices, called seismic isolators, which are very stiff in the vertical direction, to carry the dead load, and flexible in the horizontal ones, to allow lateral movements. In addition, seismic isolators usually dissipate a considerable amount of energy and provide a restoring force to limit the displacement during earthquake and the final off-set. Thus, the isolated structure assumes a quite low natural frequency (in a range where, generally, earthquakes have low input energy) and behaves like a rigid body above the isolation systems: accelerations and inertial forces, and then strains and stresses, are dramatically reduced and are almost the same at each level of the plant. This simplifies a lot the anti-seismic design of the structure and internal components and allows the standardization of the design, which become practically site-independent (for the horizontal component of the acceleration, at least). This is particularly important in the phase of development of new reactors, like those of Generation IV, when the construction site of the plant is still unknown and the economics is one of the GIF criteria. More generally, seismic isolation is an effective tool for reducing or almost eliminating the devastating effects of earthquakes on people, equipments and structures. In particular, the use of seismic isolation can provide higher safety margins against failure of equipment and structural components in case of beyond design earthquakes, because the acceleration level at which the safe shutdown occurs can be significantly increased. This is extremely important not only from the safety point of view, but also from the economics, in terms of operability of the plant. It is worth noting that seismic isolation, being quite diffused in civil applications and already known especially in seismic countries like Japan and Italy, is positively perceived by the population and its application to nuclear plants certainly should have a good effect on the public opinion. In the last years, several extremely violent earthquakes occurred all over the world as, for example, the Niigata-Chuetsu-Oki earthquake (Japan, 2007), the Wenchuan earthquake (China, 2008), those which strongly struck Haiti and Chile in 2010 and that near the east coast of Honshu, Japan (March 11, 2011), which caused a devastating tsunami. These earthquakes were well higher than the expected design event (beyond design) and some of them struck large nuclear plants. Thus, the lesson learned from these events is that the demand for seismic capacity often exceeds our current regulations by a factor of 2 or even more. This implies that enhanced design solutions and methodologies, like base isolation, will gain considerable importance. This requires a new attention to the general layout of the plant in order to give adequate protection not only to the reactor core and vessels, but also to all the systems directly or indirectly related to safety to avoid situations like that recently occurred for the Fukushima plants.

State of the art on seismic isolation in NPPs

Application to Light Water Reactors

The first application of seismic isolation to a nuclear power plant was completed at Cruas, France (see Figure 1) where 4 PWRs (with a total electric power of 3600 MWe) were isolated at the end of the '70s (the construction began in 1978 and the reactors became operative between 1983 and 1984). The choice of seismic isolation was done to keep the design unchanged with respect to other reactors already designed or built by EdF in France, in places with lower seismicity (typically 0.2 g peak ground acceleration, being 0.3 g that of Cruas). For the same reason, two 900 MWe PWR units (same model of Cruas), were provided with seismic isolation in Koeberg, South Africa (30 km north of Cape Town, Figure 2). The construction began in 1976 (even before than Cruas) but the reactors were completed in 1984-1985. It is worth noting that the first new application after Cruas and Koeberg, is represented by the Jules Horowitz Reactor, now under construction at the Cadarache Nuclear Centre site (France) with an isolation system composed by 195 neoprene bearings (900x900x181 mm size, manufactured by NUVIA, Freyssinet Group) already installed, see Figure 3).

Fig 1: the four PWR units of Cruas, France, provided with seismic isolation.

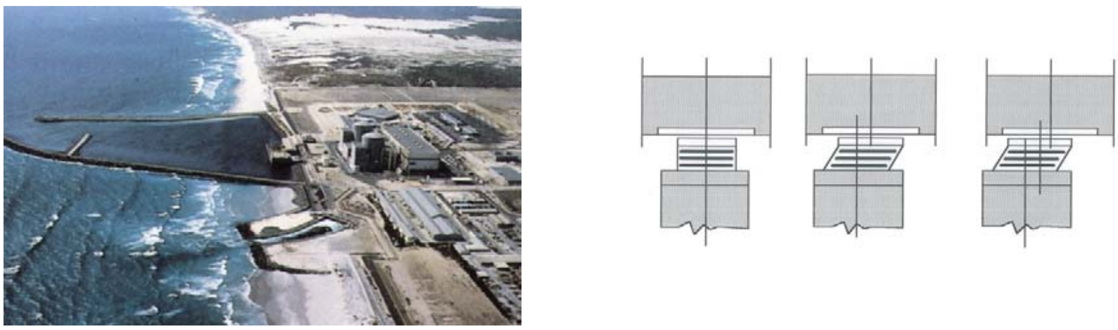

Fig 2: the two PWR units of Koeberg, South Africa, provided with a seismic isolation system composed by rubber bearings coupled with friction plates.

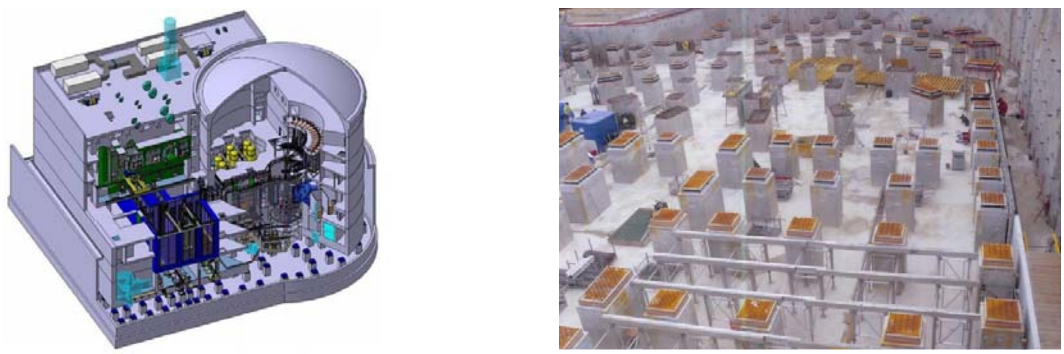

Fig 3: sketch of the Jules Horowitz reactor and view of the isolation system during installation.

In addition, the ITER (International Thermonuclear Experimental Reactor) will be erected soon with base isolation, again at the Cadarache site. Among new water reactor designs, the IRIS (International Reactor Innovative and Secure) and the 4S (Super Safe, Small and Simple) reactor, developed by Toshiba-Westinghouse, must be cited. It is worth noting that for the IRIS, lot of activities on seismic isolation, even experimental, have been carried out, especially by the Italian partners of the consortium (see [2, 3]).

The case of Liquid Metal Reactors

The studies carried out up to now have shown as the issue of seismic protection of the plant is particularly felt in Liquid Metal systems. Compact pool-type designs of liquid metal cooled systems, in fact, alleviate plant construction costs, at the same time compactness can introduce new safety issues. For the lead-cooled concepts, seismic design challenges are specifically related to the large mass of lead. Moreover, peculiar to a LFR design, besides the high density of the coolant, is the integration of the steam generators or heat exchanger equipment inside the reactor vessel: this implies the risk of a large potential load in the case of an earthquake and of a new load brought about by the Steam Generator Tube Rupture (SGTR) or Heat Exchange tube rupture accidents.

At now, several studies have been carried out. The ALMR (Advanced Liquid Metal Reactor) is a sodium reactor developed by General Electric-Hitachi Nuclear Energy in the 80's; the project was sponsored by U.S. Department of Energy (DOE). The ALMR isolated structural configuration consists of a stiff steel-concrete box structure, which supports the reactor vessel, the containment dome, and the reactor vessel auxiliary cooling system stacks. The total isolated mass is about 23,000 t, supported by 66 high damping rubber bearings made of hard compound (shear modulus G = 1.1 MPa). The Safe Shutdown Earthquake (SSE) is characterized by an horizontal and vertical peak ground acceleration (PGA) of 0.5g. The horizontal isolation frequency is 0.7 Hz, and the vertical frequency is greater than 20 Hz. ENEA participated in the verification of the design of the isolators. More information on the ALMR is given in reference [4]. The S-PRISM (Power Reactor Innovative Small Module) is a modular reactor (415 MW for each module), again developed by GE in the 80's. Of course, for this kind of reactor the standardization of the design is a very critical issue. Seismic isolation was considered the most promising solution to keep the design unchanged independently of the construction site. The reactor module was supported by 20 HDRBs which give to the system an horizontal frequency of 0.7 Hz and provide a reduction of the horizontal shear forces by a factor 3. The PGA was 0.5 g at the SSE. More information on the S-PRISM is given in references [5, 6]. It is worth noting that this project was abandoned in 1994 before obtaining the licensing and now a new design, including seismic isolation, is in progress and aims to satisfy the severe requirements of GEN IV reactors. For the STAR-LM (Secure Transportable Autonomous Reactor-Liquid Metal) reactor, now under development at the Argonne National Laboratory (ANL), the standardization of the design is a key issue even more important than for S-PRISM, also due to the severe requirements of GEN IV for lead reactors. The SSE and OBE are characterized by a PGA of 0.3g and 0.2 g, respectively. The isolation system is made of cylindrical isolators with a diameter of 1.2 m and a rubber height of 0.5 m; the isolation frequency is 0.5 Hz in the horizontal direction and 21 Hz in the vertical one. For this reactor, a study for the seismic isolation in the vertical direction (with a frequency of 1.1 Hz) is being carried out. More information on the STAR-LM is given in [7]. The KALIMER (Korea Advanced LIquid MEtal Reactor) is an economically competitive, inherently safe, environmentally friendly, and proliferation-resistant sodium cooled reactor which is now being developed by the Korea Atomic Energy Research Institute. A total of 164 HDRBs (1.2m diameter) are installed between the ground and the lower base mat in the KALIMER-600 reactor and fuel handling buildings. The seismic gap between the isolated reactor building and the non-isolated wall is about 1.2 m, sufficient to avoid contacts ("hammering") even when the plant is subjected to a beyond design earthquake with a peak ground acceleration of 1.0 g. Further information about the KALIMER is provided in [8]. The ESFR (European Sodium Fast Reactor) is under development in the framework of the European Collaborative Project CP-ESFR, with the aim of evaluating pros and cons of the loop and pool solutions. In this project, ENEA is responsible of the task *Design measures for consequence mitigation of seismic loads*, in the framework of which the seismic isolation of the whole reactor building has been proposed. Aim of the task is also the development of guidelines and recommendations to provide techniques and methods for the reduction of seismic vulnerability.

Specifically on lead-cooled systems, some preliminary studies have been carried out in ELSY FP6 and LEADER FP7 projects [12], evaluating the general plant behavior up to the vessel in pool-type LFR systems, showing that the issues of coolant sloshing, gas entrapment and core voiding are important phenomena which need a further, detailed, study. The necessity to mitigate the earthquake damaging effects has been outlined in these projects and the seismic isolation is explicitly regarded as a viability issue, as from the SNE-TP SRA.

SEISMIC ISOLATION IN LEAD-COOLED SYSTEMS: THE SILER PROJECT

SILER (*Seismic-Initiated events risk mitigation in LEad-cooled Reactors*) is research project now (June 2011) under negotiation with EURATOM in the frame of the Seventh Framework Programme. The consortium is composed by ENEA (Coordinator, Italy), AREVA (France), SCK-CEN (Belgium), FIP Industriale (Italy), MAURER-SOEHNE (Germany), JRC (Ispra, Italy), SINTEC (Italy), KTH (Sweden), BOA (Germany), IDOM (Spain), ANSALDO (Italy), IPUL (Latvia), NUMERIA (Italy), VCE (Austria), SRS (Italy), CEA (France), EA (Spain), NUVIA (France). SILER addresses all the above-mentioned seismic topics making reference to two reactor concepts: ELSY [13]and MYRRHA.

The main goal of SILER is the development and application of seismic isolators for lead-cooled reactors. Two device typologies are considered in the Project: High Damping Rubber Bearings (HDRB, Figure 4) and Lead Rubber Bearings (LRBs, Figure 5). HDRBs are composed by alternate rubber layers and steel plates, bonded together during the vulcanization phase of the isolator. The capacity of supporting the axial (vertical) forces is given by the reinforcing steel plates which hinder the radial deformation of the rubber. Horizontal (shear) deformations are allowed by the elasticity (or, better, hyper-elasticity) of the rubber, that also provides the restoring force. The shear modulus (G) of the rubber ranges between 0.4 MPa (soft compound) to 1.4 MPa (very hard compound). For civil building applications, a medium compound (G=0.8 MPa) is often used. For nuclear applications, due to the large masses to be isolated (and, consequently, the high stiffness needed), the hardest compound is often necessary. In this case, particular attention must be paid to the bonding between rubber and steel. Finally, the energy dissipation is obtained by using suitable chemical components in the rubber compounds; the equivalent viscous damping can range from 5% (natural rubber) to 15% (high damping rubber). It is worth noting that higher is the damping factor, lower is the failure limit of the isolator. Typically, natural rubber and high damping rubber fail beyond 500% and 300% shear strain, respectively. If higher damping values are needed, the use of lead rubber bearings is recommended instead of additional energy dissipaters. The isolators used for nuclear application are usually quite large, due to the high mass of the superstructure. This introduce difficulties in the manufacturing process. In fact, the abovementioned vulcanization phase requires a quite uniform temperature distribution in the whole isolator, which is more difficult to be obtained for large volumes. Thus, particular attention must be paid to the production process controls and in the qualification of the device. The insertion of one or more lead cores within a rubber bearings can increase the equivalent viscous damping of the isolator up to 25-30% (LRBs). The advantage to dissipate energy trough the lead core is that the isolator can be made in low damping natural rubber, which is more resistant to failure, as stressed above. The disadvantages are a more difficult manufacturing process and a lower re-centering capability. The isolators developed in the SILER Project will be tested in full-scale and real dynamic conditions up to failure, with the aim of carefully evaluating the safety margins in case of beyond design earthquakes.

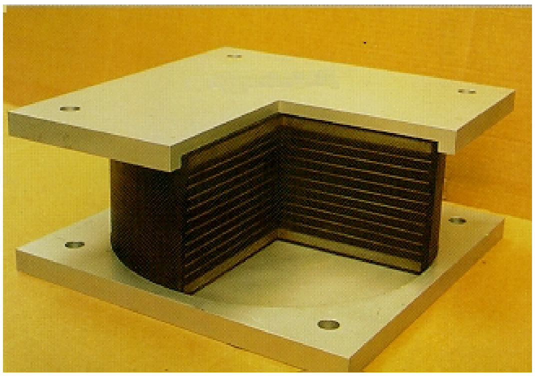

Fig 4: High Damping Rubber Bearing

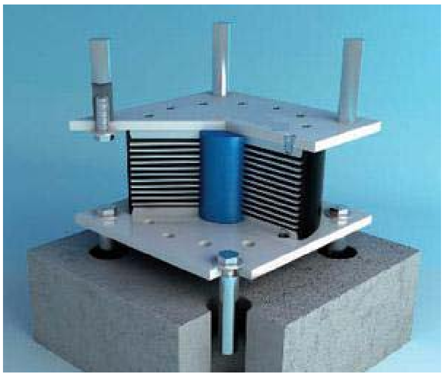

Fig 5: Lead Rubber Bearing

Interface components

The adoption of base isolation introduces significant relative displacements between the isolated and non isolated parts of the plant. Thus, a seismic gap must be present all around the isolated part and shall be adequately protected and kept free during the whole life of the structure, in order to allow the relative movements in case of earthquake. All the service networks and pipelines crossing the seismic gap shall be provided with suitable expansion joints.

Seismic gap

The seismic gap shall be covered with a weatherproof joint capable not only to absorb bi-directional horizontal displacements in case of earthquake, but also to avoid infiltrations of water in the room where the isolators are installed (not only in case of rain and snow, but also for floods and tsunamis). The seismic joint protection must also be fireproof. In fact, in case of airplane crash, some burning fuel can reach the gap; in this case it’s necessary to avoid that it reaches the isolators. Moreover, some wreck of the plane can fall over the cover gap; thus, it shall be adequately protected or designed to resist to the impact.

Expansion joints

For the regular service networks (pipes, wires and cables) several kind of expansion joints are already available on the market, used in the isolation of civil buildings, and no particular design solutions are necessary for applications in nuclear plants. When the whole nuclear island is isolated, one of the most critical systems crossing the seismic gap is the pipeline which goes to the turbines (containing hot and pressurized steam). Expansion joints similar to those needed in this case were tested in the framework of the INDEPTH project [9] for an isolated tank of a petrochemical plant. The technology for this kind of devices already exists also for high temperatures and pressure. It is worth noting that a smart disposition of two gimbals and one angular joints along the pipeline provide 6 degree of freedom to the system and can accommodate even huge displacements with very limited rotations (and then stresses) of the joints.

Horizontal fail safe system

Even in case of beyond design earthquakes, the isolators shall never loose the capability of supporting the vertical load. Thus, the adoption of an horizontal fail safe system to limit the isolator deformation must be foreseen. It is also strongly recommended that the fail safe system includes some shock absorber (for example a rubber bumper) to soft the hammering between the isolated building and the foundation. These devices are not present in the Cruas, Koeberg and Jules Horowitz Reactors, and are seldom used in civil buildings.

Guidelines and standardization procedures

Aim of SILER is also the development of guidelines proposal for the design, qualification, in-service inspection, maintenance and replacement of isolators.

The design and construction of nuclear plants are regulated, all over the world, by well known standards (issued by the NRC, IAEA, JAEA, etc.) that also include the seismic conventional design, but without seismic isolation. Moreover, there are several standards for the design and construction of isolated civil buildings like EURODE 8 and others. Finally, there are some standards addressed to the design, manufacturing and testing of seismic isolators for civil applications, like EN 15129, which came into force in 2010 in all European countries [10]. But no standard, at present, is specifically addressed to seismically isolated nuclear reactors or to isolators to be used in such plants (apart the Japanese standard cited in [11], that, unfortunately, is available in Japanese, only).

The lack of existing specific standards is one of the most important problems in the application of seismic isolation to nuclear plants, especially for what concerns the qualification of the isolators. New guidelines and/or recommendations are necessary to regulate the qualification of these very critical components, maybe developed starting from the existing ones.

EN15129 is going to be mandatory (August 2011) in all European countries for any kind of application where seismic isolators are used. However, it is not specifically addressed to nuclear plant. Thus, EN15129 can be used as a sort of *minimum requirement* in nuclear applications and improvements shall be done. To this aim, some activities are already foreseen in SILER, for showing that EN15129 is basically suitable for applications in nuclear plants but with some, not always minor, improvements. In particular it is recommended:

a) To design the isolator in order to have a rubber shear strain at the SSE lower than 100%. In this way the isolators will have the minimum stiffness at SSE and will have large safety margins in case of beyond design earthquakes.

b) To perform the type tests on full scale isolators and to test them with real three-directional dynamic excitations.

c) To perform the factory tests on the whole isolator production (concerning the vertical load capacity, at least).

CONCLUSIONS

The paper presented the world state-of-the-art of seismically isolated nuclear reactors (included new designs), focusing on the main problems encountered in the application of this technology to lead reactors, such as the need of manufacturing and testing very large isolators and to design interface components, and the lack of standards specifically addressed to isolated nuclear reactors.

It is recognized that for HLM-cooled reactors the seismic risk mitigation is a key issue to be addressed for the development of such systems, to guarantee the safe operation of such systems.

In general, it can be stressed that:

- All the present applications or recent new designs of isolated NPPs use rubber isolators (with or without lead plugs) acting in the horizontal directions only. These devices are the best candidate to isolate nuclear plants.

- The isolation in the vertical direction of the whole nuclear island is not possible, yet; at present, if necessary, this kind of protection shall be limited to some critical components and equipments through suitable energy dissipaters (spring-dashpot devices).

- The technology for pipe expansion joints connecting the isolated part of the plant with the conventionally founded one, is almost already available, but requires some improvements.

- The adoption of an horizontal fail-safe system is strongly recommended, to avoid the isolator failure or instability in case of extremely violent earthquakes (beyond design).

- EN15129 can be used as reference standard for the design, qualification, in-service inspection, maintenance and replacement of isolators. However, since this standard is not specifically addressed to NPPs, EN15129 shall be used as a sort of “minimum requirement” and some improvements shall be done.

The SILER Project, that hopefully will start on November 2011, will deal with the most critical issues related to the seismic isolation of lead-cooled reactors and will certainly provide significant improvements with respect to the present state-of-the-art also by means of experimental campaigns on full-scale isolator (tested with dynamic three-directional excitations up to failure) and expansion joints.

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