SEISMIC ISOLATION OF ADVANCED NPPs

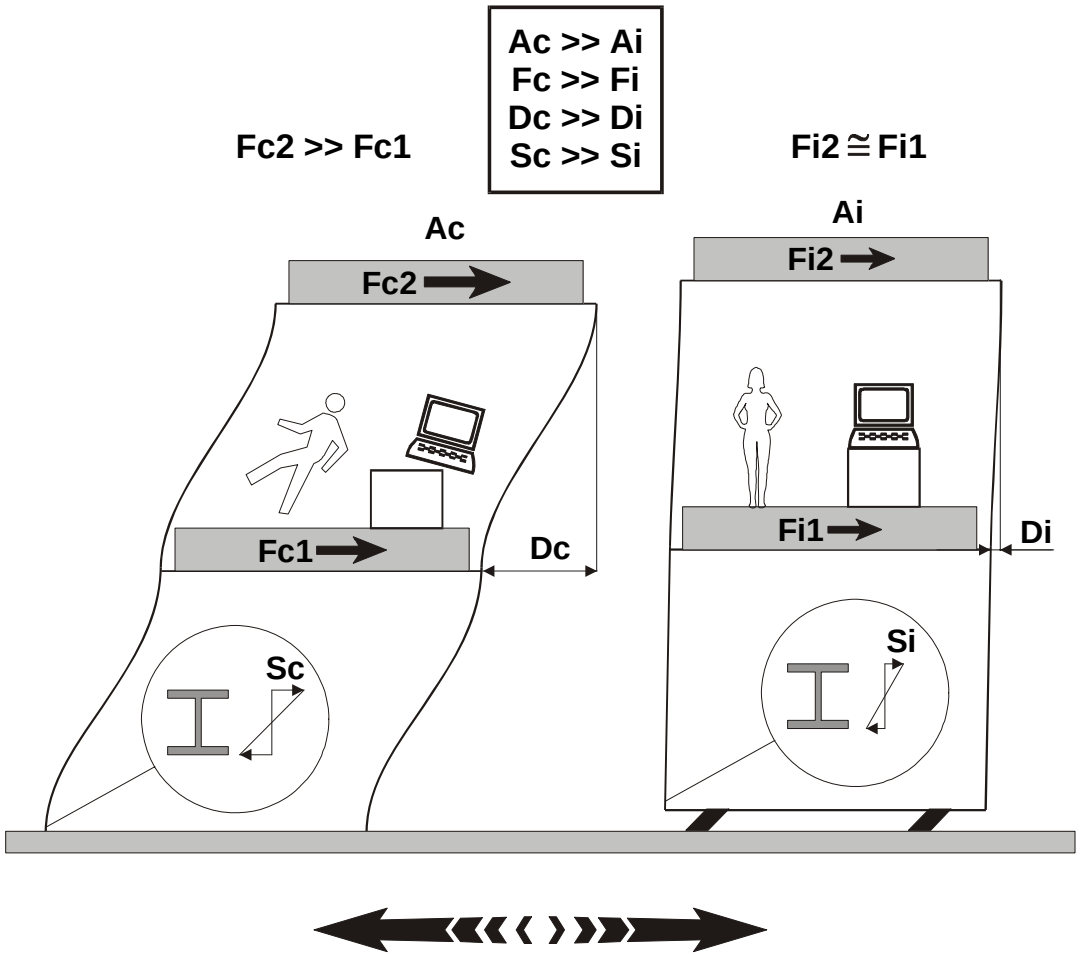
State of the Art and most recent Designs (IRIS and ESFR)

Massimo FORNI- ENEA

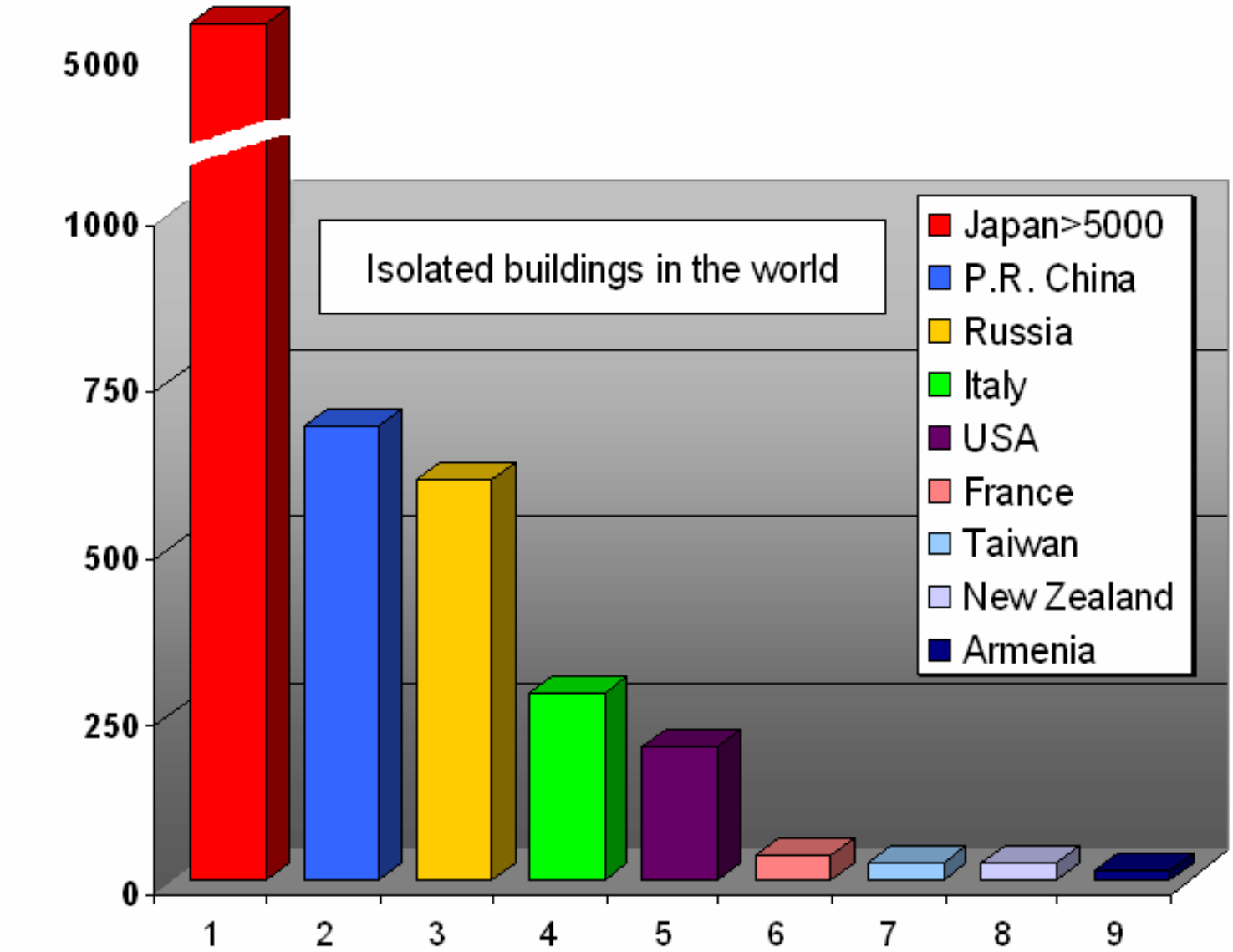
Technical Meeting on Seismic Safety of NPPs
Scuderie Estensi Tivoli, Italy, March 25 – 26, 2010

Seismic Isolation technique consists in the insertion, between the ground and the base of the structure, of suitable devices having the following functions:

1)Support the vertical load
2)Allow for horizontal displacements
3)Provide a restoring force
4)Dissipate energy

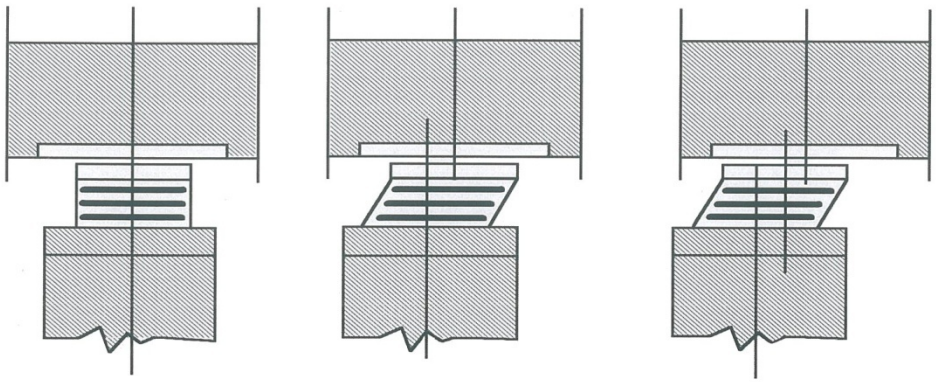


Shaking table test on a seismically isolated mock-up (BRITE-EURAM Project, 1993).


Isolated buildings in the world
5000
1000
750
500
250
0
1
2
3
4
5
6
7
8
9
Japan>5000
P.R. China
Russia
Italy
USA
France
Taiwan
New Zealand
Armenia

Cruas, France (1983-85), 4 PWRs - 3,600 PTFE Isolators (500x500x65 mm)

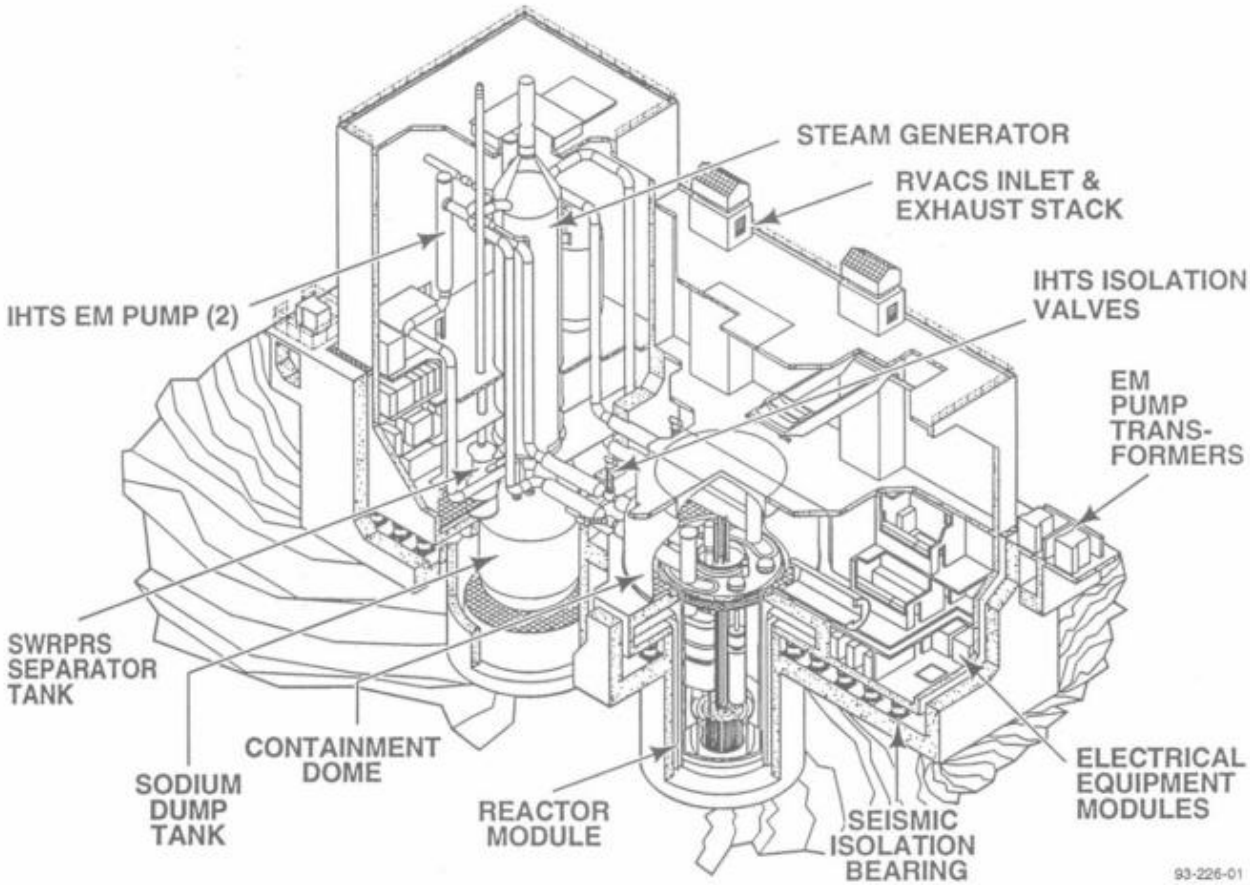
Koeberg, South Africa (1984-85), 2 PWRs - 1,800 rubber bearings (700x700x130 mm) coupled with sliders



ALMR (Advanced Liquid Metal Reactor) project

The ALMR isolated structural configuration consists of a stiff rectangular steel-concrete box structure, which supports the reactor vessel, the containment dome, and the reactor vessel auxiliary cooling system stacks.

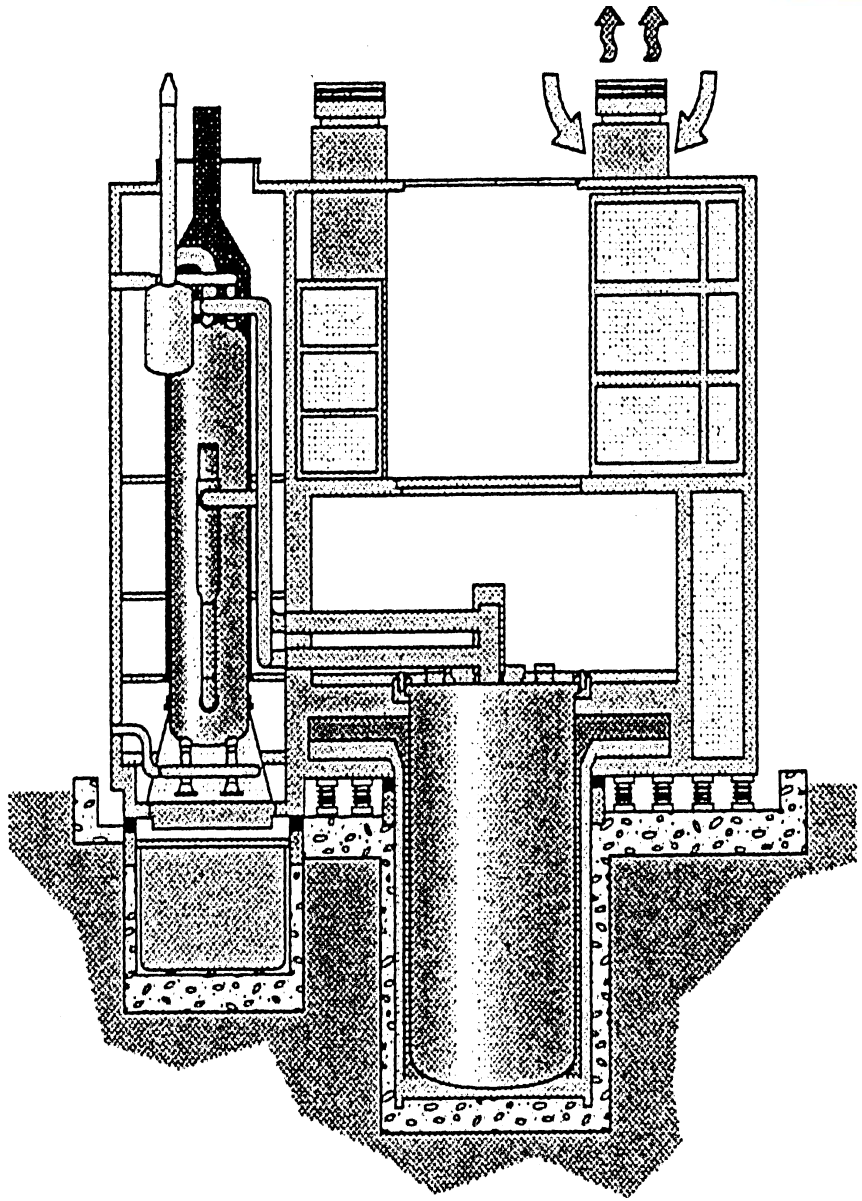
Project sponsored by U.S. Department of Energy (DOE)
Safe shutdown earthquake (SSE) with a horizontal and vertical PGA up to 0.5g.
The total isolated weight is about 23,000 tons and is supported on 66 high damping rubber bearings
The horizontal isolation frequency is 0.7 Hz, and the vertical frequency is greater than 20 Hz.



ALMR Reactor & Steam Generator Facility General Arrangement

S-PRISM project

- Isolated reactor modules designed by General Electric;
- natural frequencies: fhor=0.70 Hz; fvert= 21 Hz;
- SSE with a horizontal PGA up to 0.5g;
- displacement at 0.3g is 191 mm;
- lateral load reduction > 3.



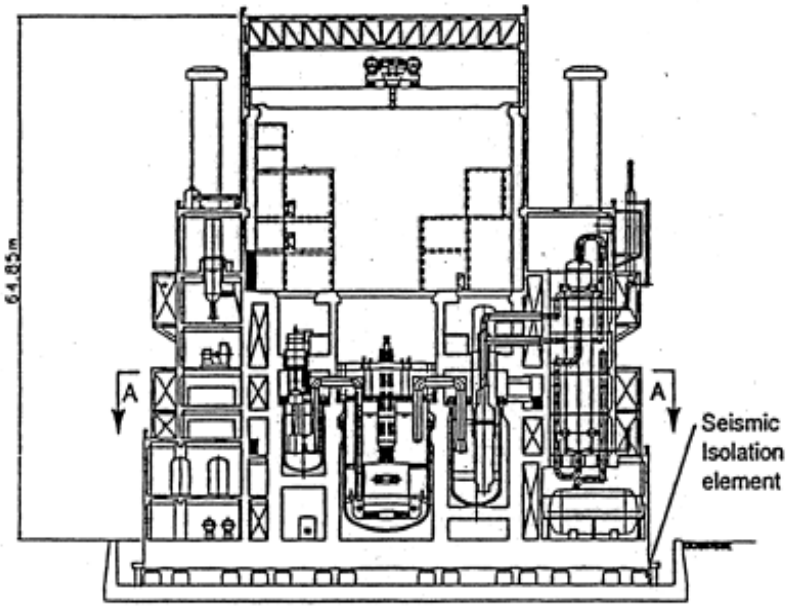
DFBR (Demonstration Fast Breeder Reactor), JAPD

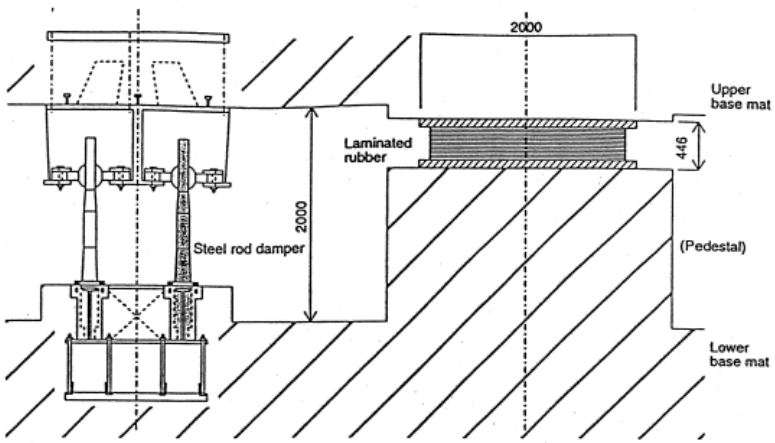
2D seismic isolation design:

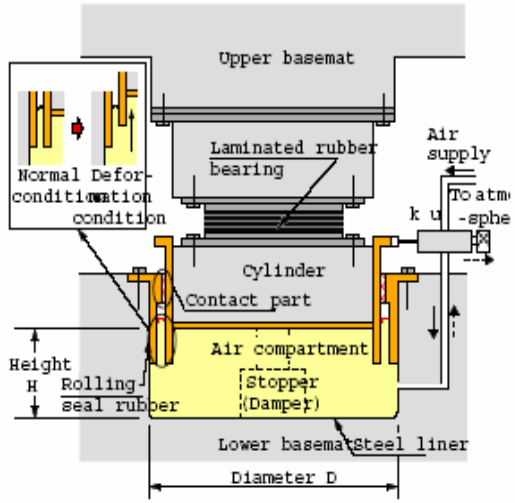
- 246 elastomeric isolators (up to 1,6m DIA) + steel dampers;
- Frequencies: f hor=0.5 Hz, f vert>20 Hz.

3D seismic isolation design:

- elastomeric isolators (225 mm thick, 1600 mm DIA) realize the horizontal isolation system (period 2.8 s);
- air springs realize independent vertical isolation system (period 2 s); service pressure of the air compartment is 1.6 MPa and service vertical load is 9800 kN.

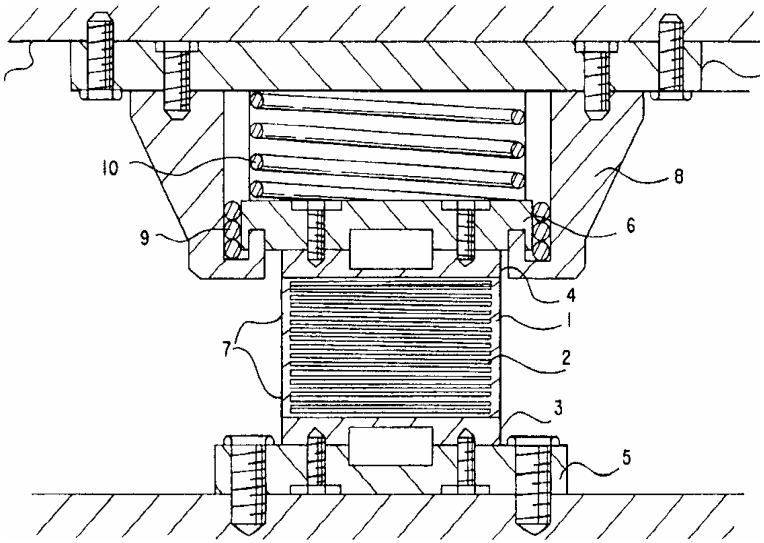


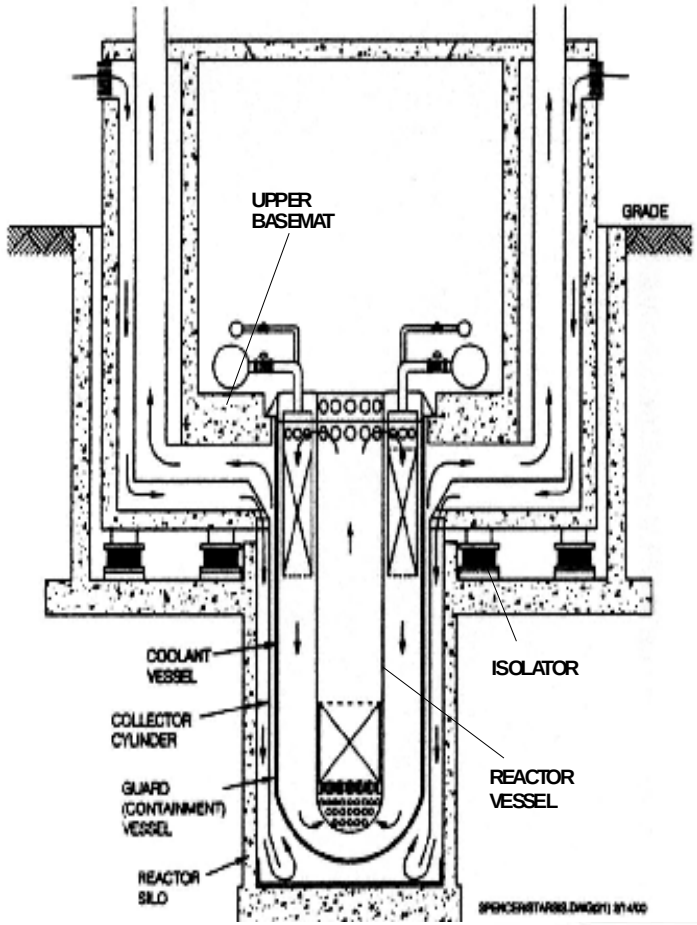




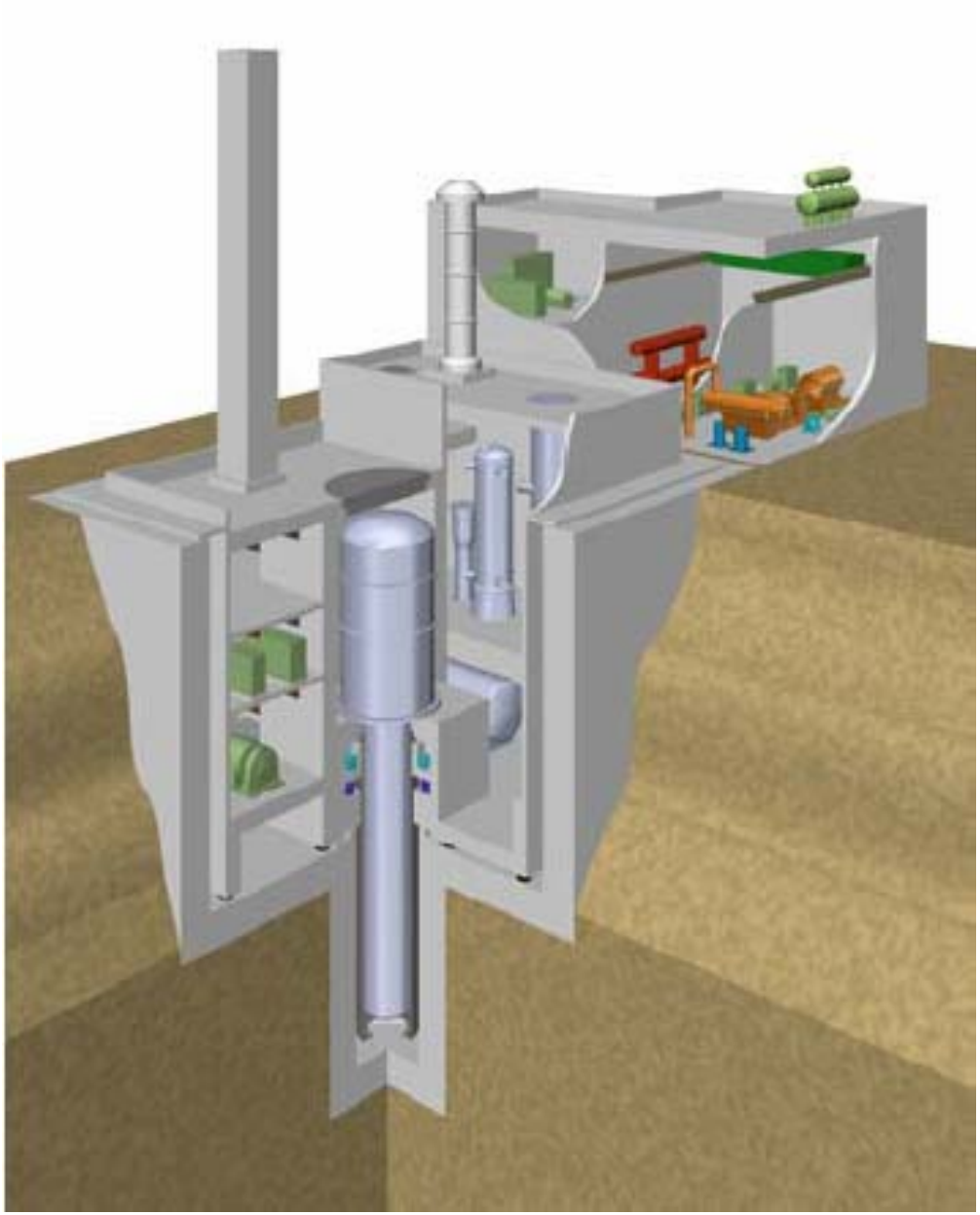
STAR-LM Secure Transportable Autonomous Reactor-Liquid Metal

- Safe shutdown earthquake (SSE) with a horizontal PGA of 0.3g and a vertical PGA of 0.2g;
- 2D seismic isolation system: 1200 mm DIA, 500 mm thick elastomeric isolators; fhor=0.5 Hz, fvert=21 Hz;



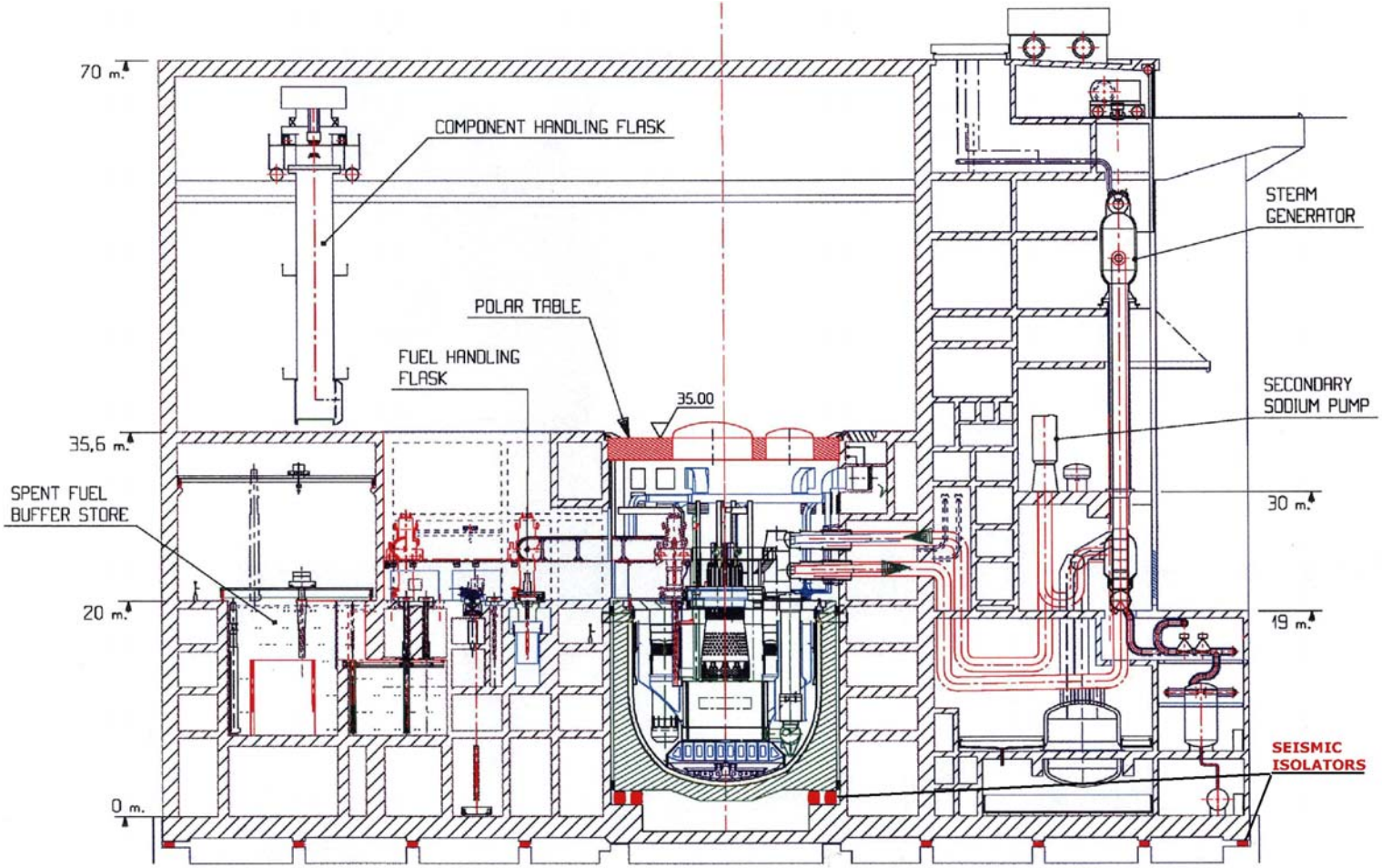


- 3D seismic isolation system: HDRB isolators for horizontal loads, helicoidal springs for vertical loads; fhor=0.5 Hz, fvert=1.1 Hz.

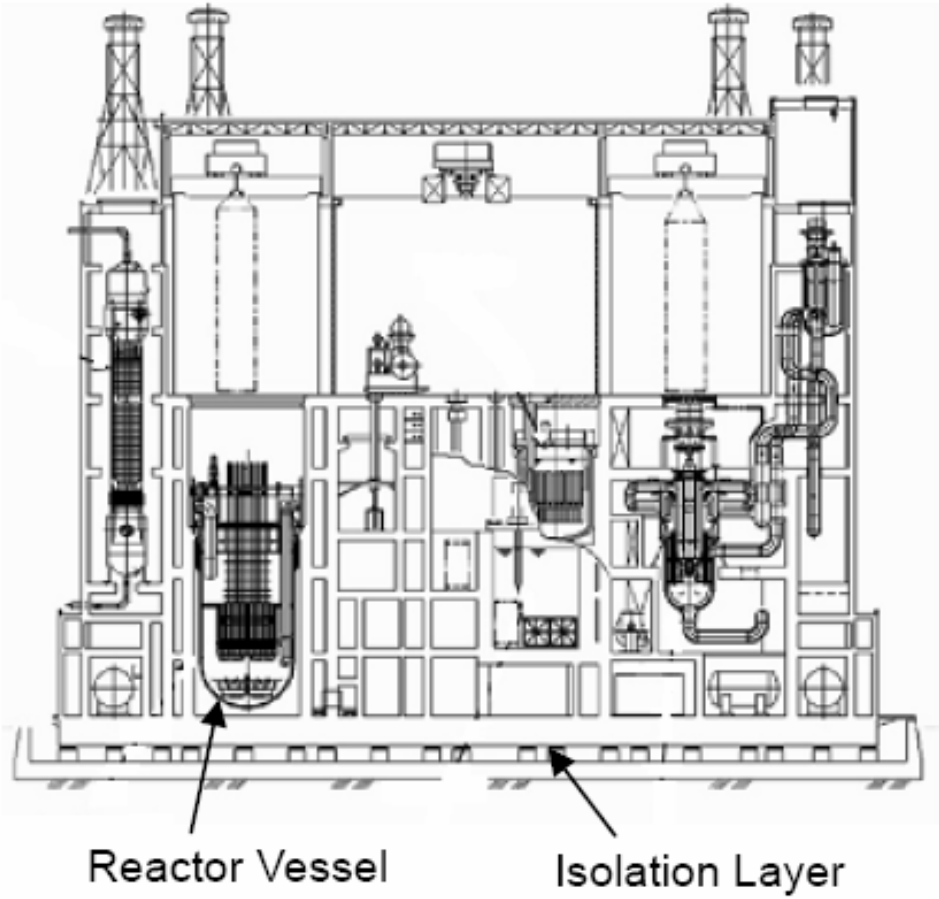


4S Nuclear Reactor (Super Safe, Small and Simple) proposed for the Galena site, Alaska

EFR (European Fast Breeder Reactor)

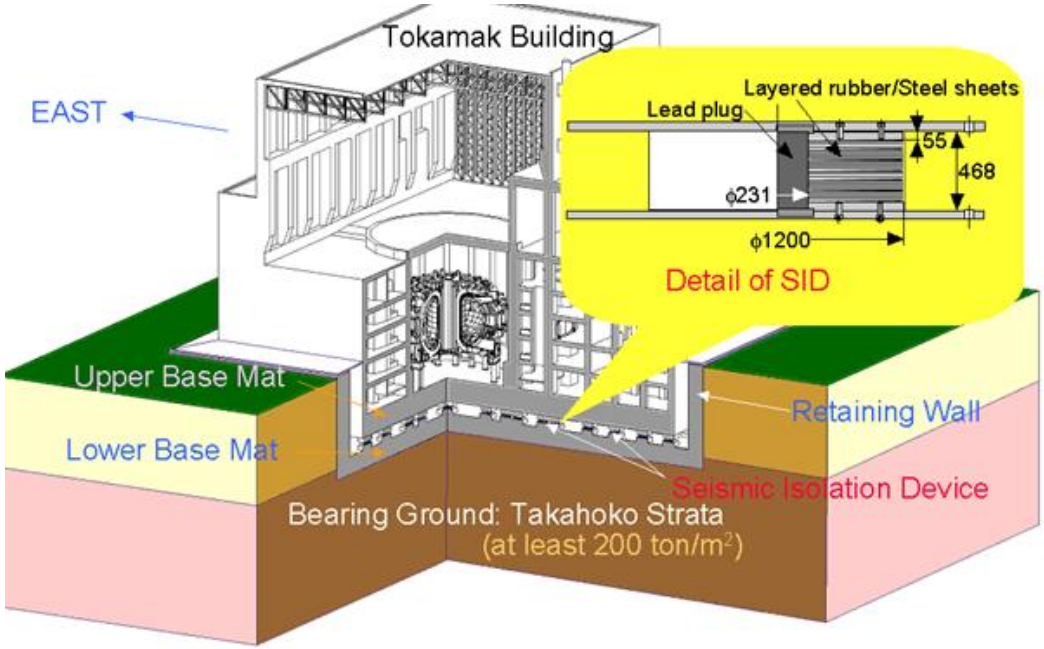


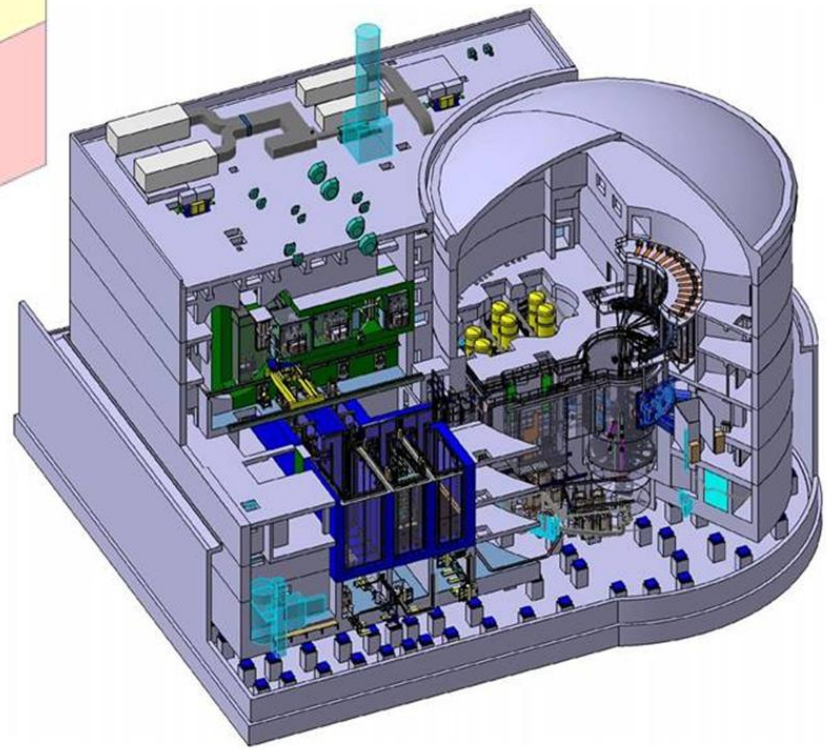
The EFR reactor vault is separated from a common raft by spring bearings to reduce the vertical seismic loads. The raft is separated from horizontal ground motions by elastomeric isolators.



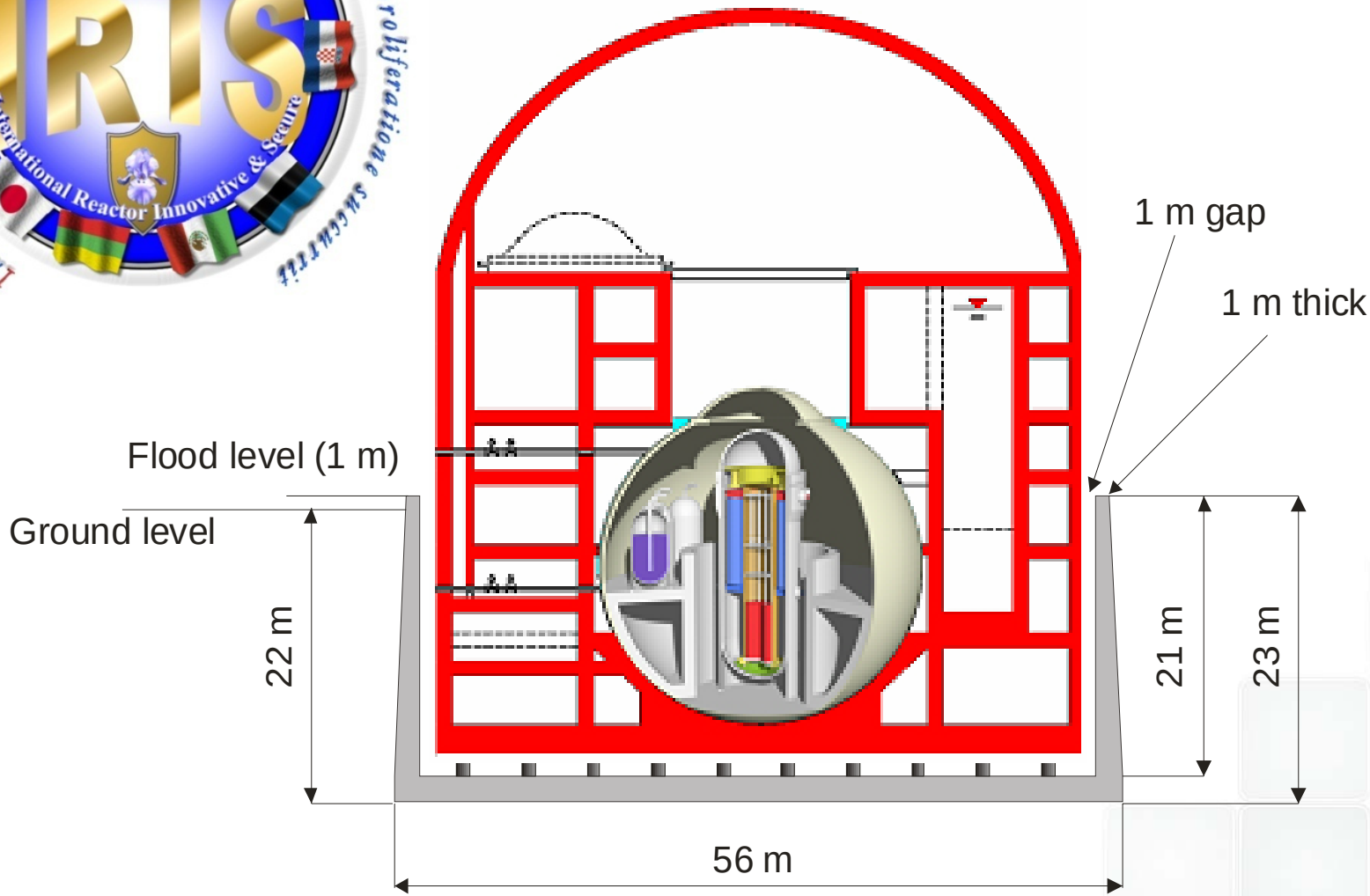
In Japan a wide ranging experimental campaign is in progress on the seismic isolation of FBR using the world largest three-dimensional shaking tables “E-Defense” of National Research Institute for Earth Science and Disaster Prevention of Japan

ITER (International Thermonuclear Experimental Reactor), being seismically isolated at the French Cadarache Nuclear Center, together with the Jules Horowitz Reactor





IRIS - International Reactor Innovative and Secure



International Team working on the seismic design of IRIS

- Westinghouse
  - Lead; IRIS design main responsibility; layout development
- ENSA
  - Reactor vessel design
- ENEA
  - Design of the seismic isolation system; tests on scaled isolators; licensing
- University of Pisa and ENSA
  - Analytical effort: FEM of IRIS building
- Politecnico di Milano
  - Analytical effort: fragility analysis
- Tokyo Institute of Technology
  - Impact on licensing

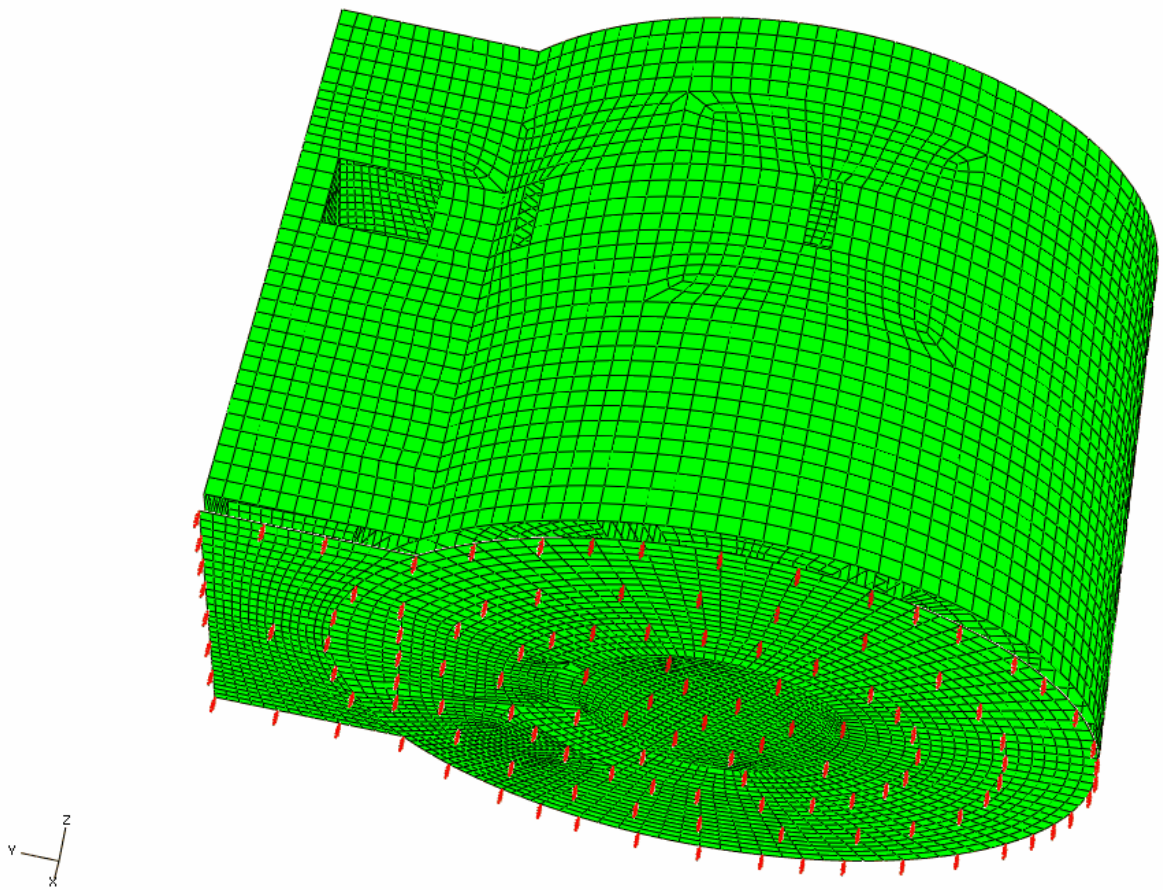
Safety-by-design™ is the approach adopted for the design of the International Reactor Innovative and Secure (IRIS)

- elimination **by design** of some of the main accident scenarios classically applicable to Pressurized Water Reactors (PWR)

- reduction of either consequences or frequency of the remaining classical at-power accident initiators

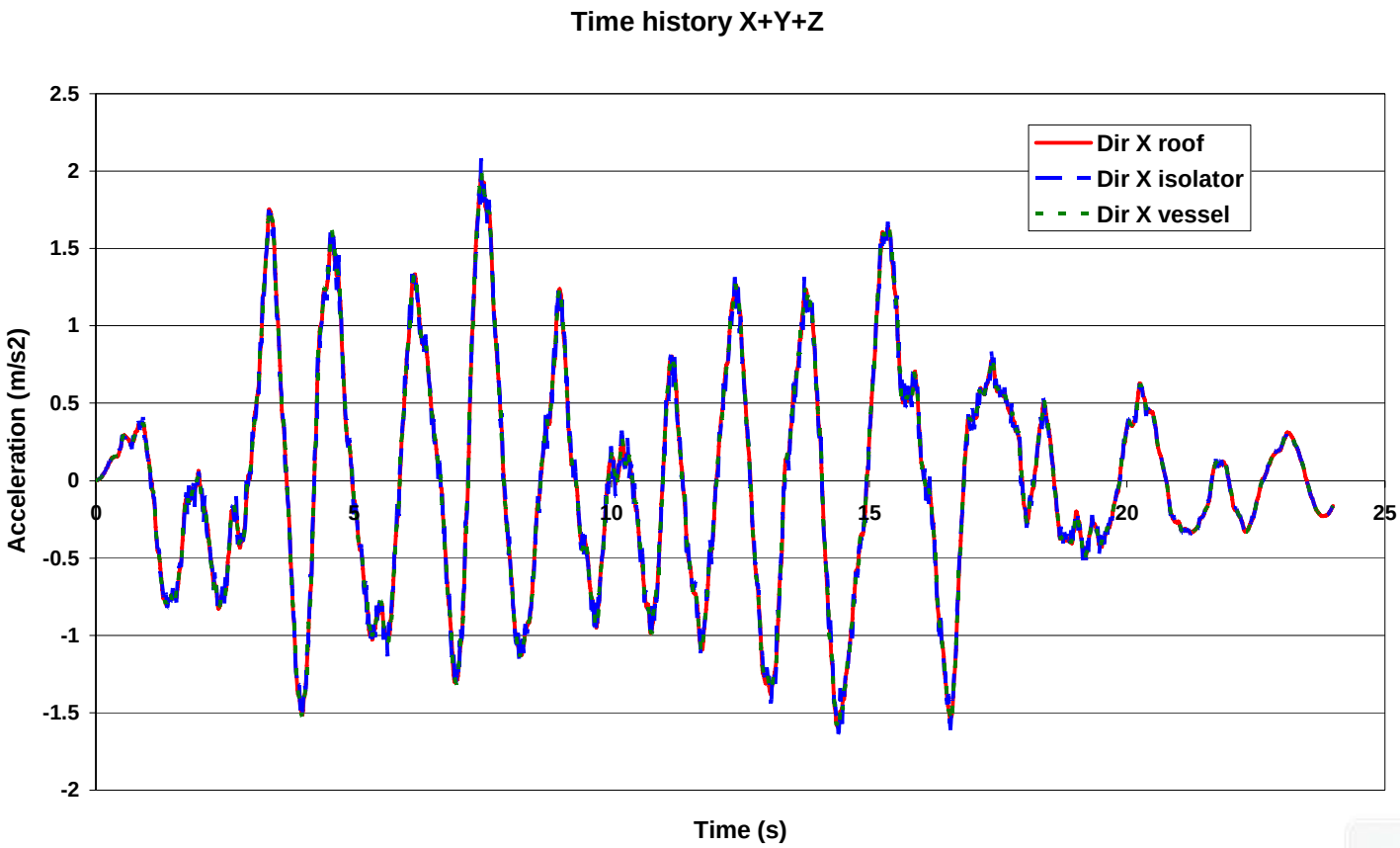
⇓

As a result of such strategy the Core Damage Frequency (CDF) from at-power internal initiating events was reduced to the 10^{-8}/ry order of magnitude



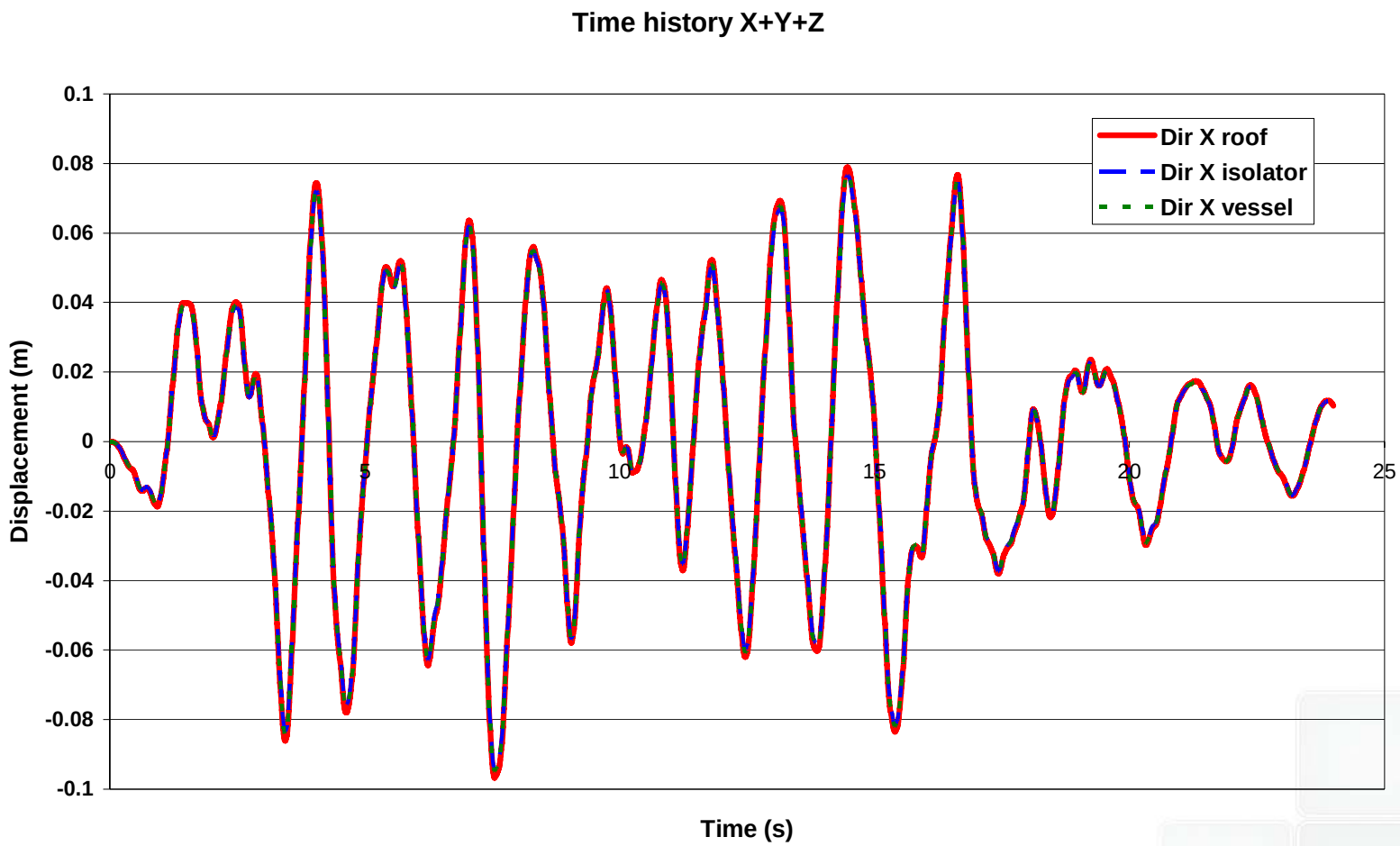
The present design solution foresees 99 HDRBs of 2 diameters (1000 & 1300 mm), 100 mm rubber height and 1.4 MPa rubber shear modulus. The stiffness centre of the isolation system coincides with the center of mass of the structure so to avoid eccentricity effects (rotations around the vertical axis). During earthquake the building moves like a rigid body with the same acceleration at any level (no amplification).

Preliminary Analysis: Acceleration of the isolated NSSS building under the design 3D earthquake (0.3g peak)

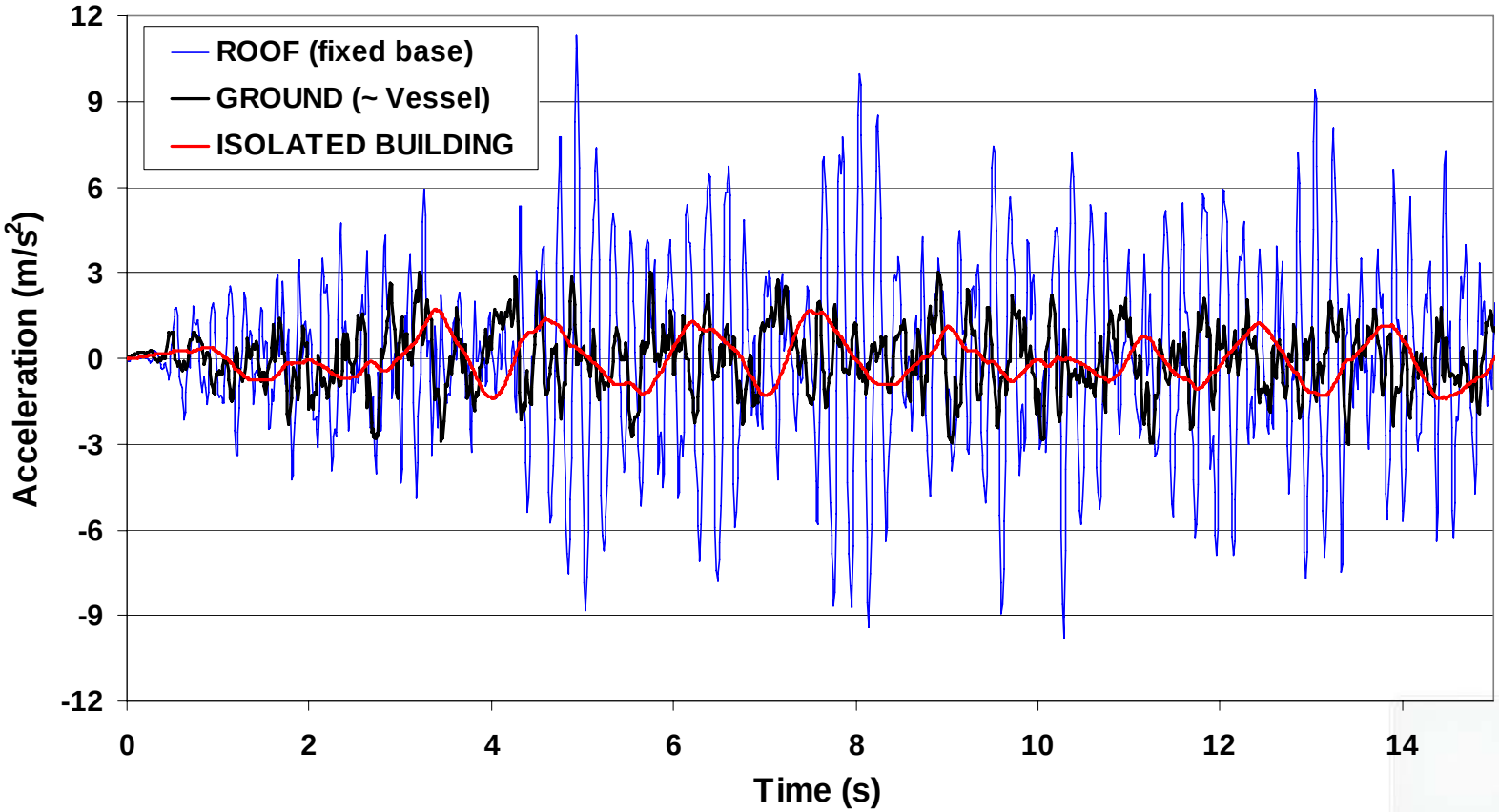


The building behaves like a rigid body (same acceleration from the base to the top) with a max acceleration of 0.2 g and a max displacement of 10 cm.

Preliminary Analysis: Displacement of the isolated NSSS building under the design 3D earthquake (0.3g peak)



The isolation system can reduce the acceleration of the building (and then the inertial forces on the components) by a factor 1.5 ÷ 2 at the vessel attachment level and even 5 ÷ 6 at the roof level.

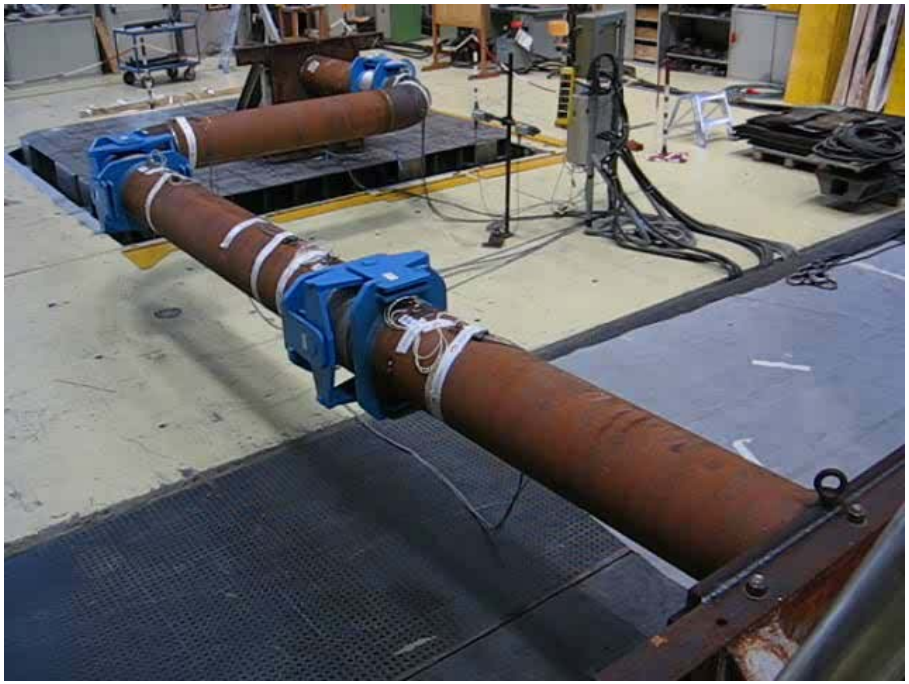


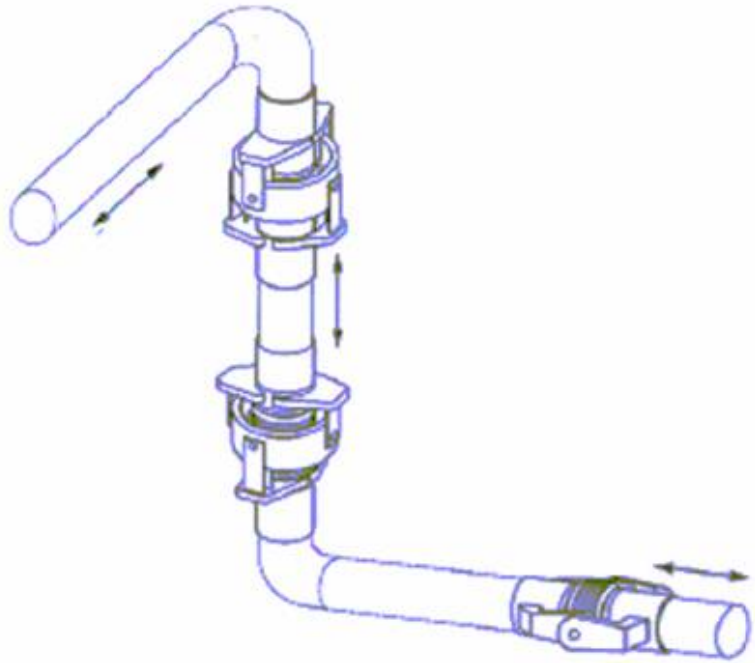
The reduction of the absolute acceleration of the isolated structured is paid with an increment of the relative displacement between the structure and the ground, which can be very important and must be carefully considered in the design of the connections.

New isolated school of San Giuliano di Puglia, Italy

Expansion joints for pipelines

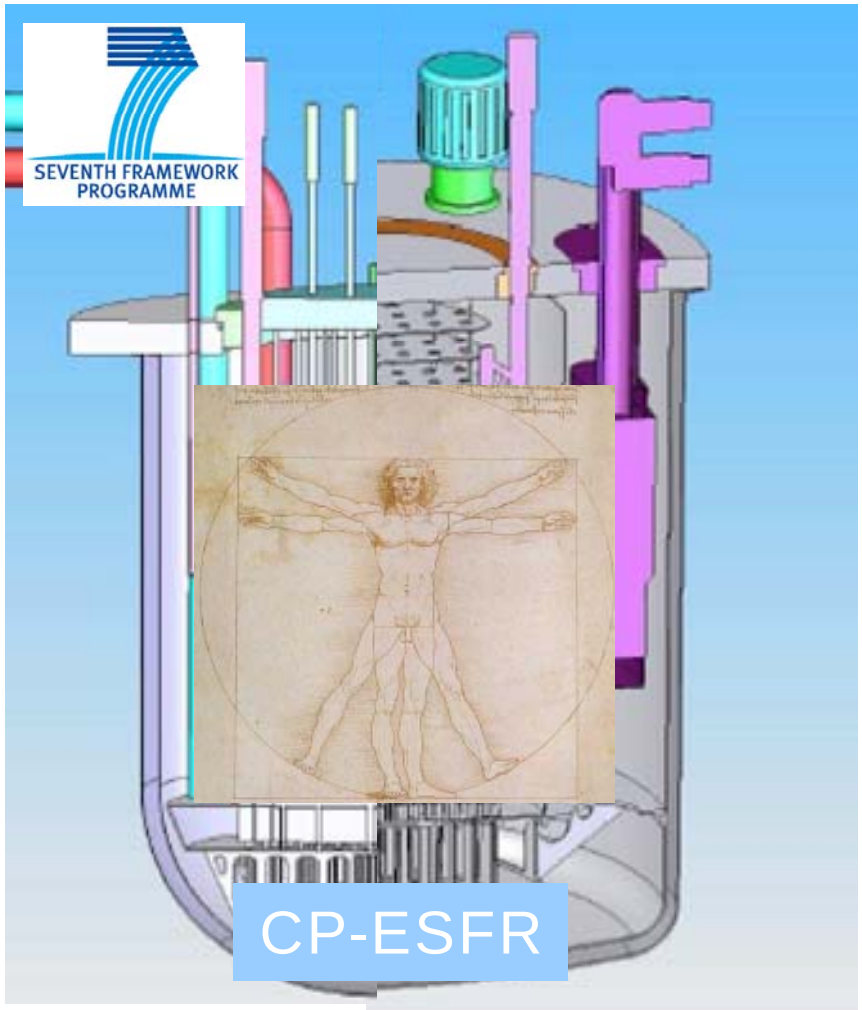
‘3-pins’ System made of 1 Angular and 2 Gimbals Expansion Joints



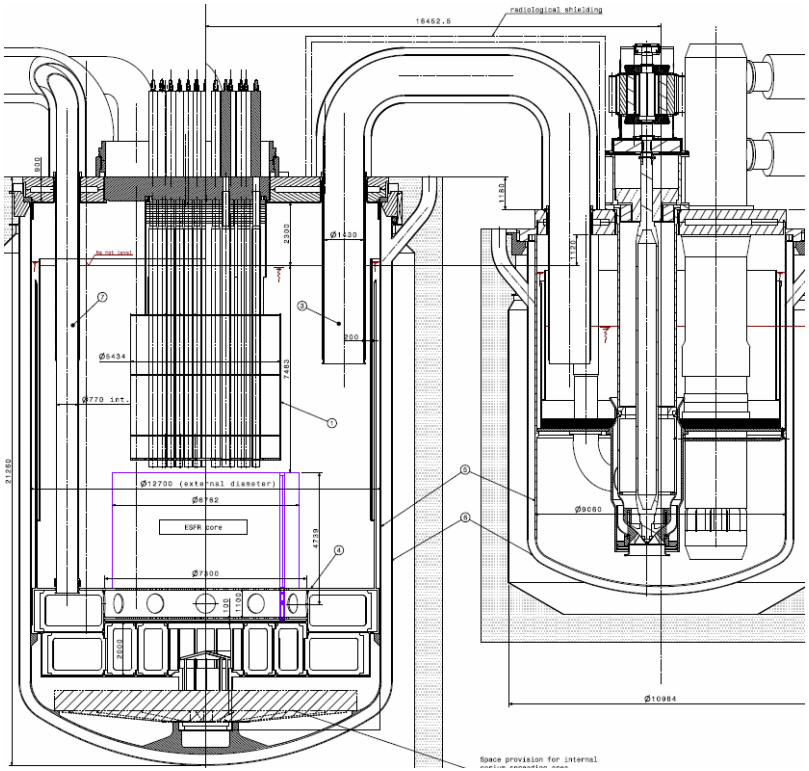


Three-pins expansion system designed for a full-scale pipeline of a petrochemical plant (connecting an isolated LNG tank) during a shaking table test up to 80 cm relative displacement (INDEPTH EC Funded Project)

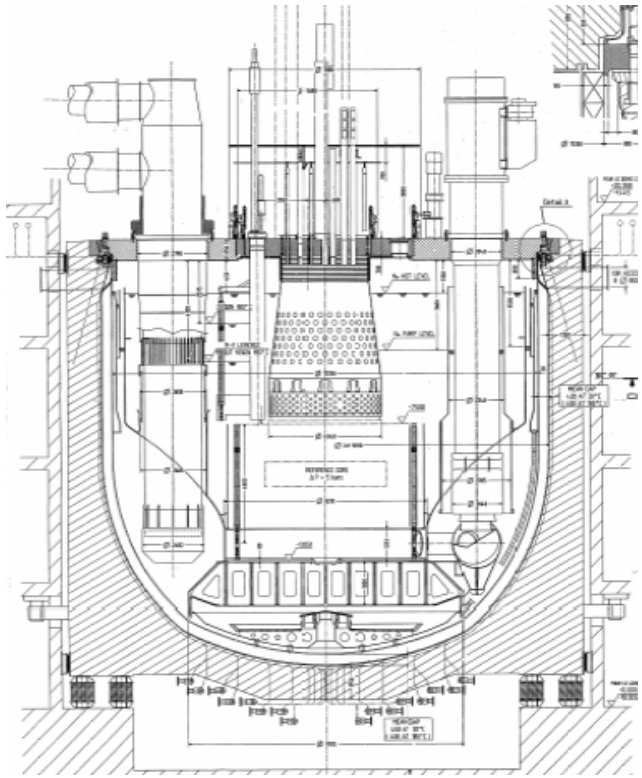
Collaborative Project for a European Sodium Fast Reactor



CEA, AMEC, ANSALDO, AREVA NP, CESI-R, CIEMAT, DFGE, EDF, EA, ENEA, EVM, FZK, FZD, JRC – ITU, JRC – IPSC, JRC – IE, NRG, NRI, PSI, SENER, Uni-Ka, Uni-Rm, UPM, IRSN, ENSA, ACCIONA, IPUL


radiological shielding
16462.6
Ø1430
Ø6434
Ø770 int.
Ø12700 (external diameter)
Ø6782
ESFR core
Ø7300
Ø9680
Ø10984
21260
4739
Space provision for internal

Loop



Pool

CP-ESFR Project

Sub-projects (4) → Work Packages (6÷8) → Tasks (6÷8)

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Task 3.2.4
Design measures for consequence mitigation of seismic loads

↓

Guidelines and recommendations aimed at providing techniques and methods for the reduction of seismic vulnerability with complementary studies in order to evaluate the consequences of mitigation dispositions

ENEA is going to propose to EC a new Collaborative Project

Seismic and other External Risks Mitigation in GEN-IV Reactors

SERIM-G4

Call Identifier: **FP7-Fission-2010**
Activity/Area: **Reactor Systems: Cross-cutting aspects for nuclear systems**
Topic: **Fission-2010-2.3.1: R&D activities in support of the implementation of the Strategic Research Agenda of SNE-TP**

AIMS

-Development and manufacturing of different typologies of isolators for both sodium and lead reactors, and their qualification through full-scale tests.

- Analysis of the behaviour of the whole isolated buildings and the most critical components like vessel and pipelines up to beyond design earthquakes.

- Design of the isolated foundation and related joints and connections.

- Evaluation of the technical/economical benefits through comparisons with conventionally founded plants.

- Development of guidelines for design, installation, inspection, maintenance and replacement of isolators in GEN IV reactors.

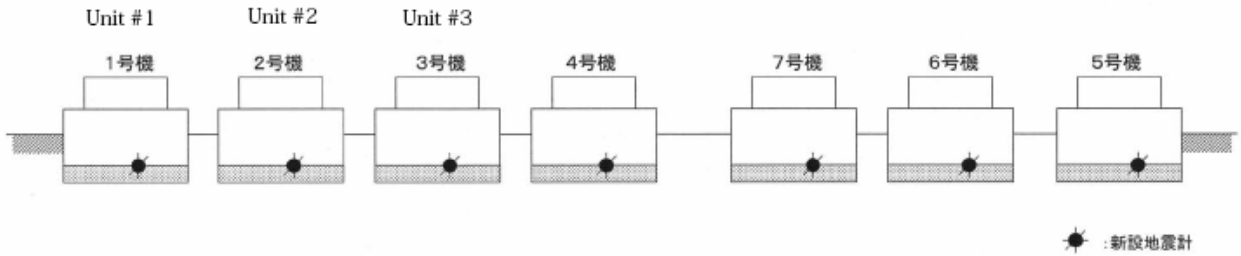
- Knowledge transfer to Gen III LWR systems .

CONCLUSIONS

Advantages of seismic isolation:
- 'Rigid body' behavior of the structure: reduction of the acceleration (and then inertial forces and stresses), which is constant on the whole building and the internal components
-Same performances guaranteed independently of the site seismic conditions: standardization of the design of the building and the components (only the design of the isolators should change)

Disadvantages:
- Additional foundation slab and containment wall for the part underground
- Free gap all around the building to allow for the seismic movements
- Expansion joints on piping between the isolated structure and the ground

Kashiwazaki-Kariwa Nuclear Power Plant, strongly damaged by the Niigata-Chuetsu-Oki earthquake of July 2007, still out of service



Maximum Observed Acceleration, in gal
観測された最大加速度 (単位:ガル)

	観測値		南北方向	東西方向	上下方向
○	1号機	最下階(B5F)	311	680	408
	2号機	最下階(B5F)	304	606	282
	3号機	最下階(B5F)	308	384	311
	4号機	最下階(B5F)	310	492	337
○	5号機	最下階(B4F)	277	442	205
○	6号機	最下階(B3F)	271	322	488
	7号機	最下階(B3F)	267	356	355

○ 7月16日お知らせ済み(新設地震計による観測記録)

【スクラム設定値】水平方向120ガル、上下方向100ガル

Maximum Acceleration in Design Analysis, in gal
設計時の加速度応答値 (単位:ガル)

	設計値		南北方向	東西方向	上下方向
○	1号機	最下階(B5F)	274	273	(235)
	2号機	最下階(B5F)	167	167	(235)
	3号機	最下階(B5F)	192	193	(235)
	4号機	最下階(B5F)	193	194	(235)
○	5号機	最下階(B4F)	249	254	(235)
○	6号機	最下階(B3F)	263	263	(235)
	7号機	最下階(B3F)	263	263	(235)

※上下方向については、( )内の値を静的設計で用いています。

This column for NS component
EW component
UD component
This column for NS component
EW component
UD component (static analysis)