AREVA EPR reactor

Technology, performance, project delivery

Jean DHERS
R&D Vice President of AREVA's Nuclear Equipment Business Unit,
NAMRC R&D Board member, Visiting Professor at the University of Manchester

YGN Introduction to Nuclear New Build
July 22nd, 2015

AREVA

Agenda

- 1- EPR Design
- 2- Current EPR Projects
- 3- “FOAK” Lessons Learned
- 4- EPR Licensing worldwide
- 5- Efficiency & Performance

AREVA

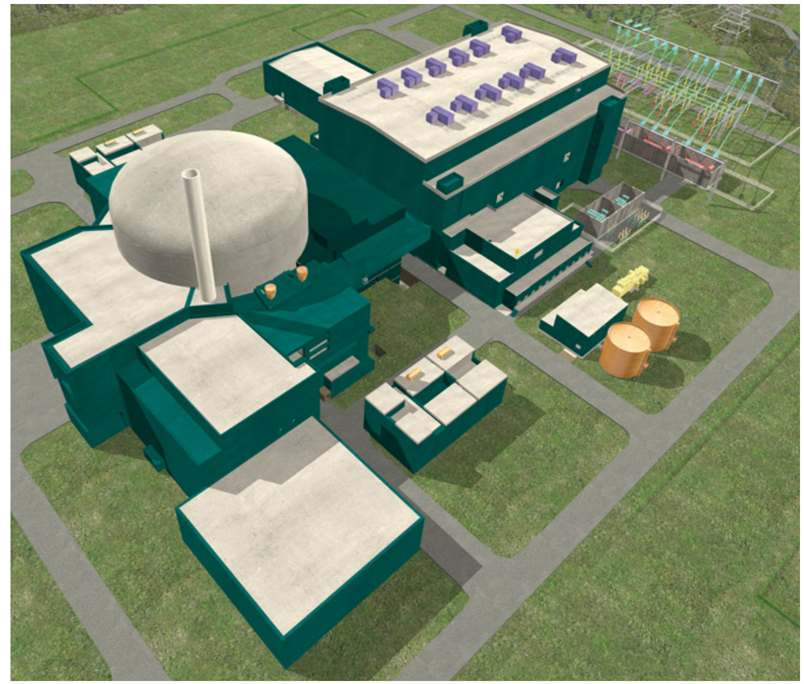
The EPR reactor, direct descendant from the French and German nuclear technology

KONVOI ~1,300 MWe

- Emsland ('88)
- Isar 2 ('88)
- Neckar 2 ('89)

N4 ~1,500 MWe

- Chooz 1&2 ('99)
- Civaux 1&2 ('00)



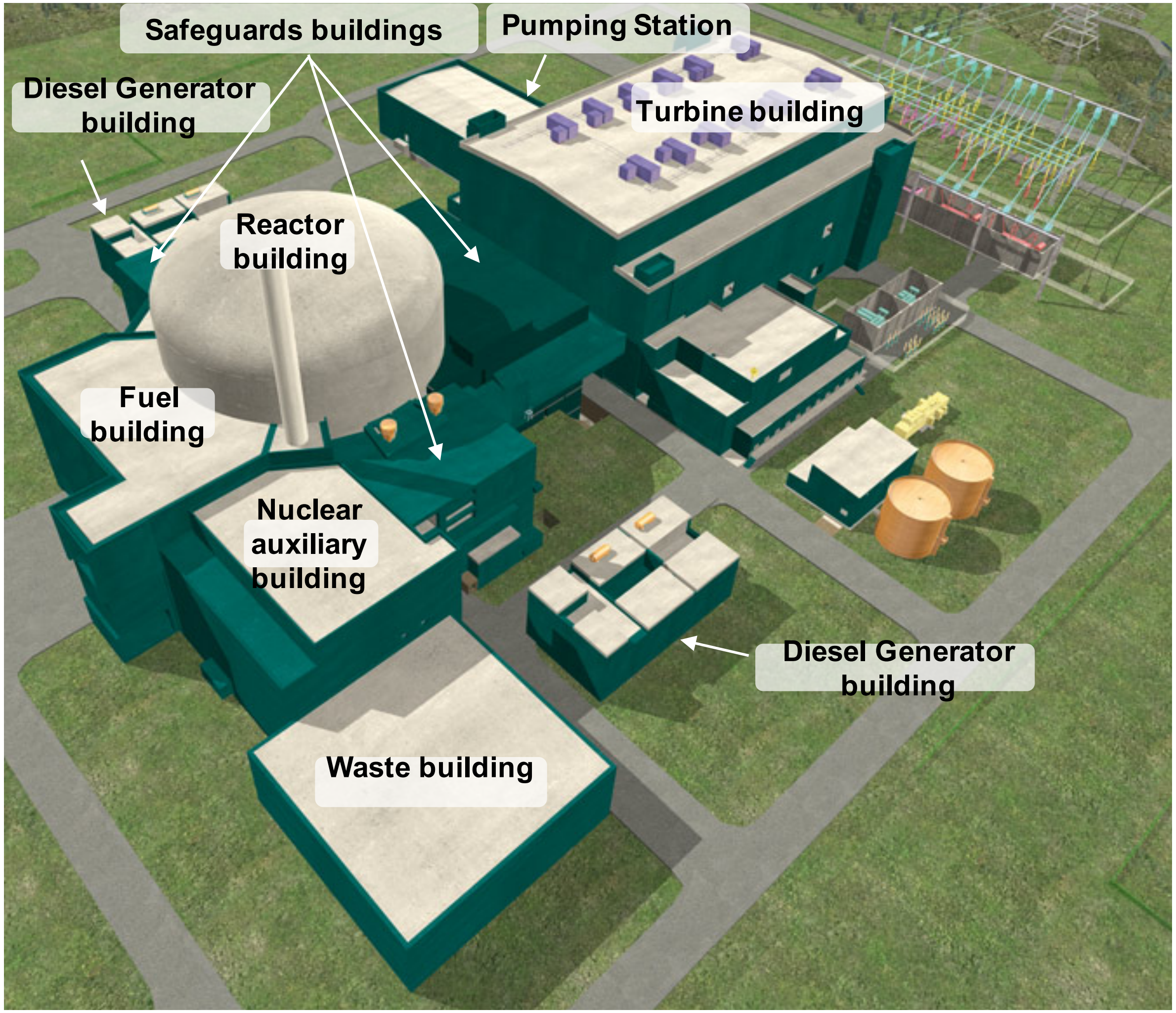
Proven and evolutionary technology

EPR Main characteristics

- **Power:**
  - **4,590 MWth (core thermal power)**
  - **About 1,650 MWe (generated electrical power)**
  - **High efficiency: up to 37%**
- **Short outages (Target design availability: 92%)**
- **Steam pressure: 77 bar**
- **Radiation Protection**
  - **Low collective dose: < 0.5 man.Sievert/yr**
- **Fuel cycle length: up to 24 months**
- **Design service life: 60 years**

AREVA

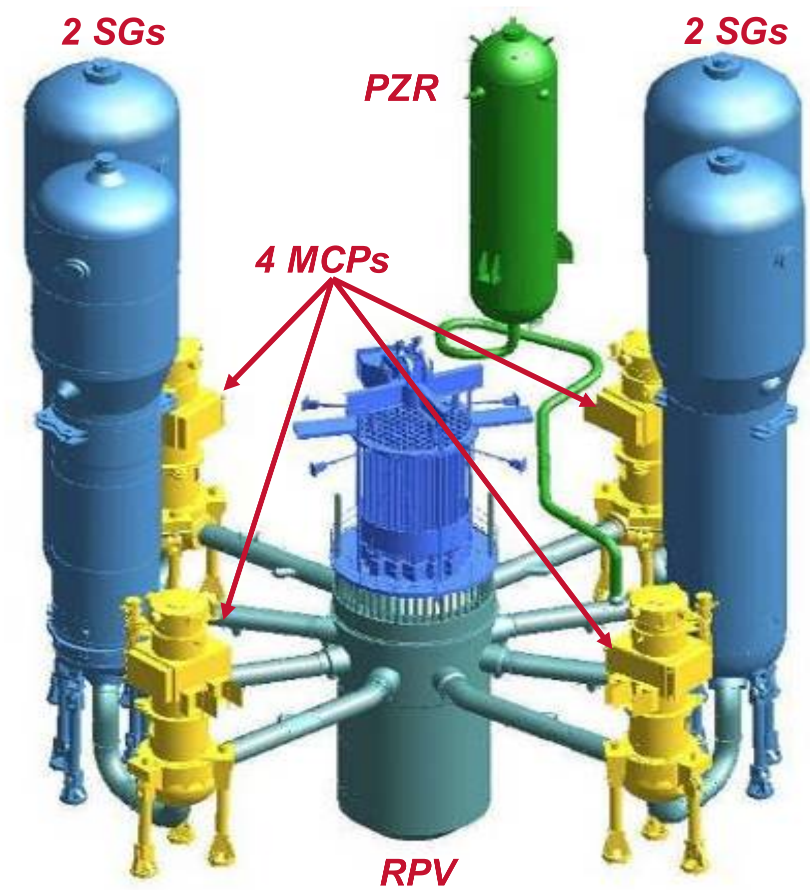
General Arrangement of the Buildings (typical)



EPR Main Primary System

- Primary System with a 4-loop configuration
- Main components enlarged as compared to those in operation
- Extensive use of forgings with integrated nozzles
- Materials resistant to corrosion and cracking (tubes in alloy 690)

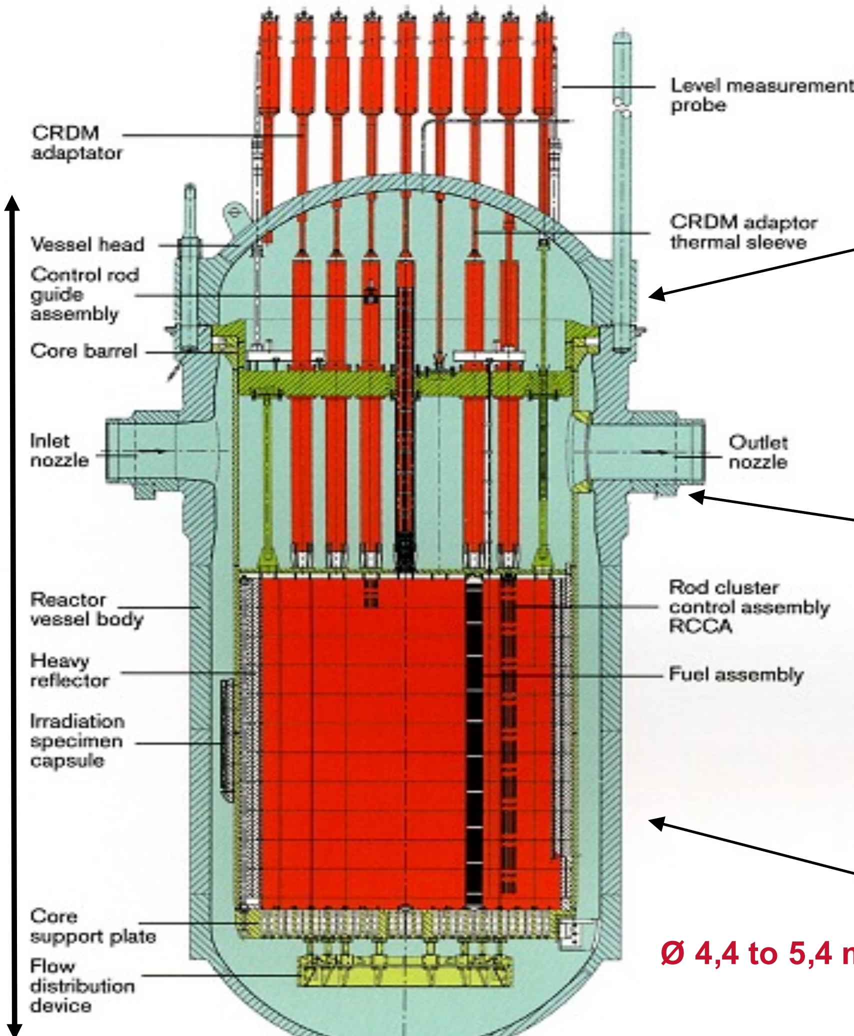
Proven design components



RPV: Reactor Pressure Vessel, SGs: Steam Generators
MCPs: Main Coolant Pumps, PZR: Pressurizer

Reactor Pressure Vessel

12,3 to 13,1 m

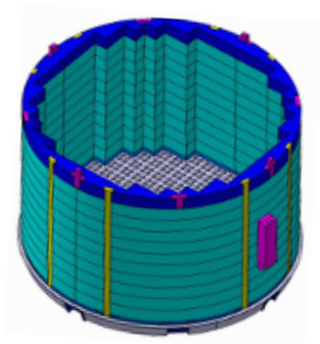


Ø 4,4 to 5,4 m

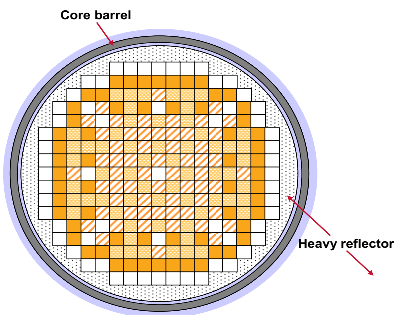
Weight : 313 to 526 t

The EPR has been designed to minimize its environmental footprint

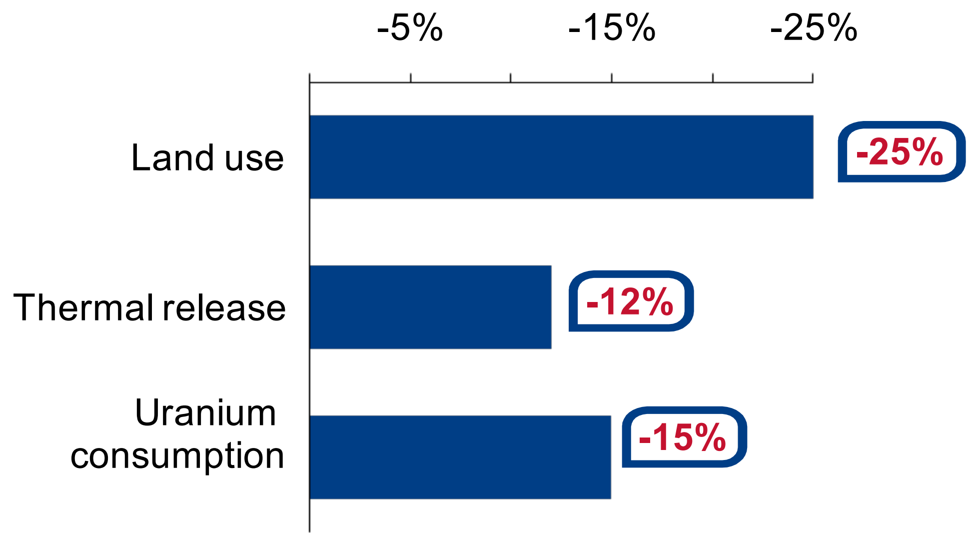
Heavy neutron reflector



Large core

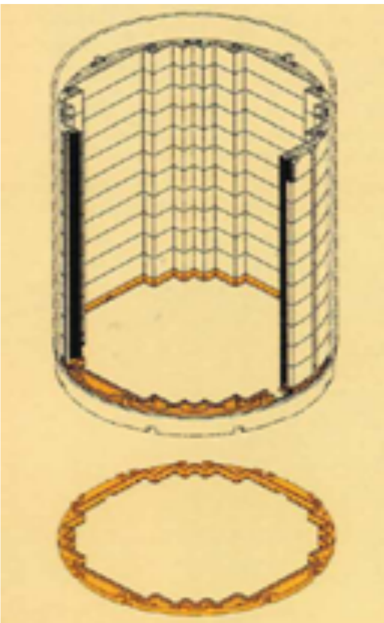


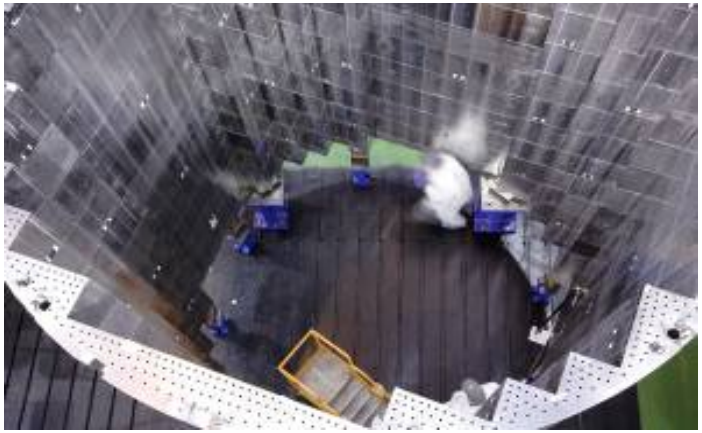
Comparison of environmental footprints EPR versus Gen 2 reactors*

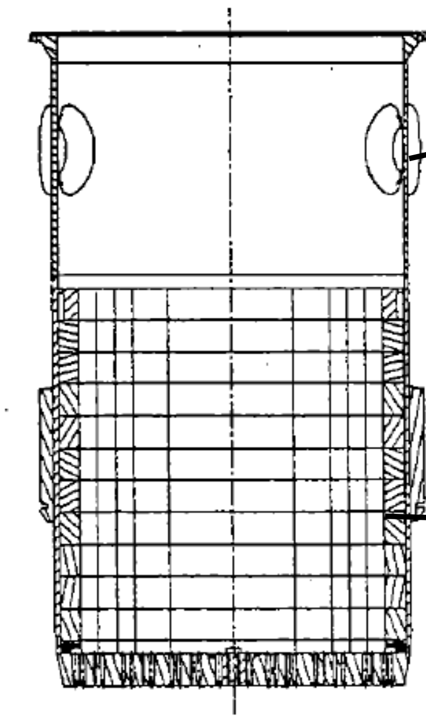


Source: AREVA, comparison done per MWh
* 900 MW, CPY reactor

EPR^{TM} Stainless Steel internals







- *High: ≈ 10,5 m*
- *Diameter : ≈ 4,9 m*
- *Weight : ≈ 180 T*

Generation III has learned lessons from 3 major events

Three Mile Island
(1979)
Accident involving core meltdown

Reducing the probability of a severe accident involving core meltdown

Chernobyl
(1986)
Spread of radioactive substances

Limiting the impact on local communities in the event of a severe accident

9/11
(2001)
Terrorist attack using commercial aircraft

Resistance to a commercial air crash (heavy aircraft)

AREVA

EPR Safety approach

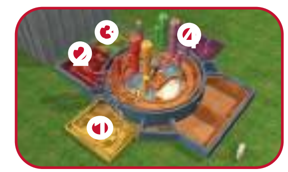
- **The Design of the Safety Systems is based on Redundancy, Diversity and Complementarity principles**

Diversified Emergency Diesel Generators

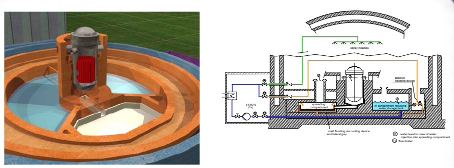
Diversity
(against Common Cause Failures)

Complementarity
(between active and passive systems)

Redundancy
(against single failure)



4 train systems in 4 Safeguard Buildings



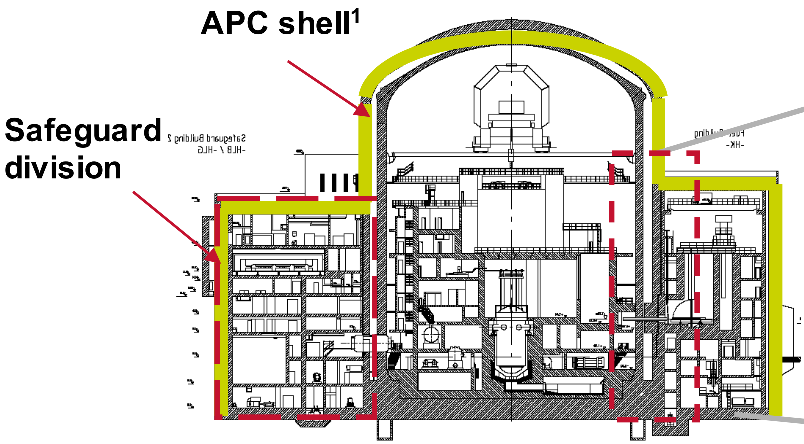
Core Catcher & Containment Spray

The EPR is designed to resist to exceptional events and prevent damage to the surroundings

AREVA

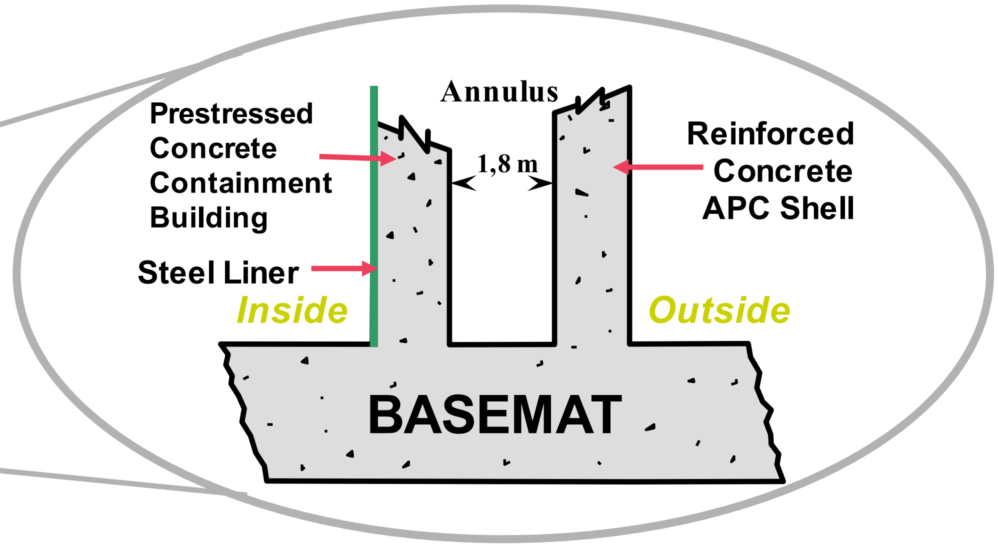
Structural resistance to major hazards

Critical buildings



- APC shell & earthquake resistance
- Doors designed to resist external explosions & floods

Reactor building



- Pre-stressed concrete containment
- Steel liner

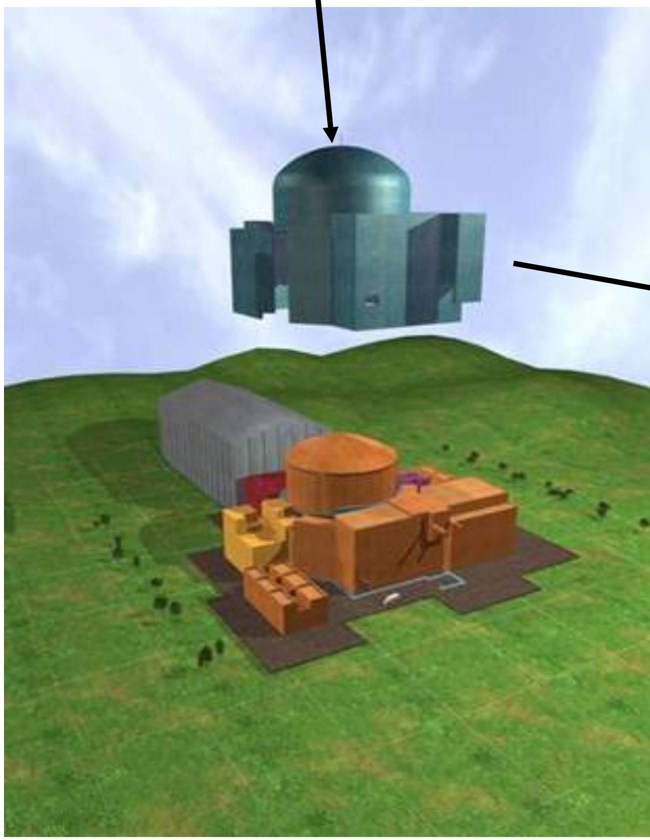
➔ Resistance to external (impacts) and internal hazards (leaks, high temperature…)

Design robustness: the EPR™ design can be compliant with a vast variety of sites

1- Air Plane Crash resistant Shell

Protection against AirPlane Crash

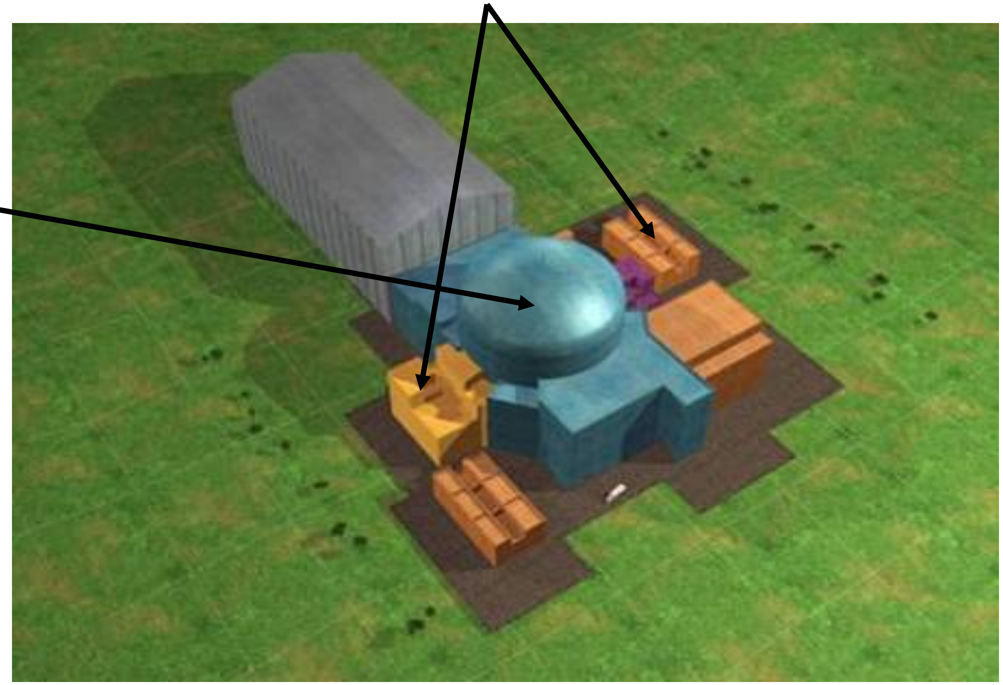
Outer shell protection resistant to APC loads



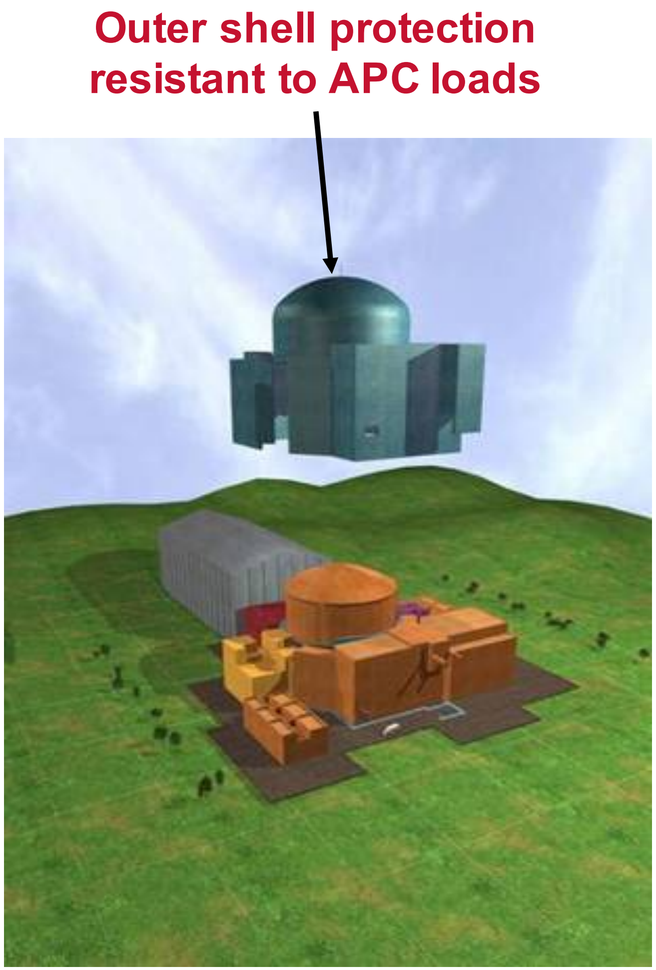
Load cases

Military and commercial large airplane

Protection by geographical separation



Protection against Earthquake



- Protection by APC resistant shell

- Equipment at the lowest level

Robustness of cooling capability

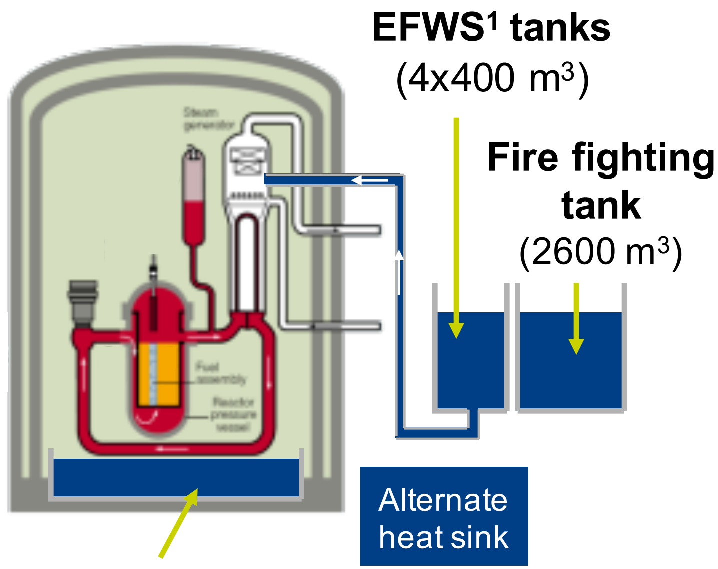
The core can be cooled using only one diesel generator, one safety train and without external heat sink

Multiple cooling systems

4 Safety trains

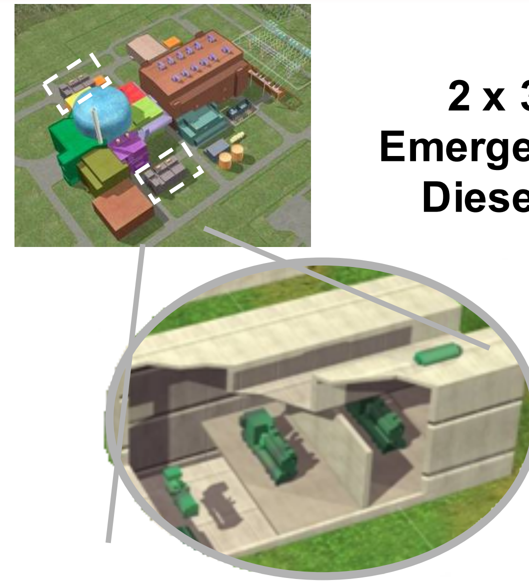
4 independent safeguard trains each of them capable to extract decay heat alone

Multiple water supply sources



Each train has two cooling sources

Multiple emergency power sources



2 x 3 Emergency Diesels

- 2 separate buildings located on each side of the reactor building
- 3 Emergency Diesel Generators in each building (2 different types)

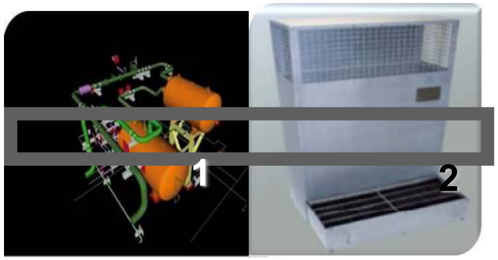
High robustness of cooling systems : redundancy, diversity, complementarity at all stages

AREVA

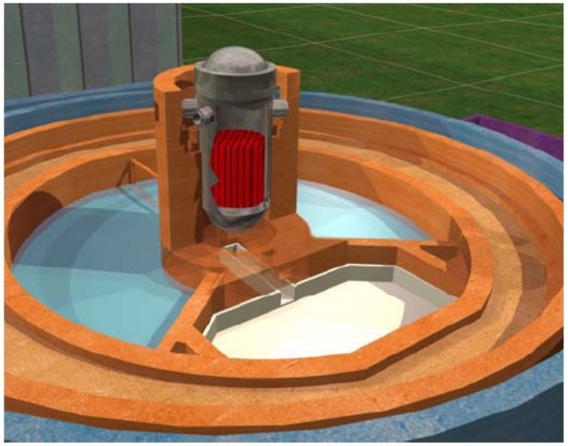
Prevention of environmental damage

Double containment

Filtered venting system (1)
Autocatalytic recombiners (2)



Core catcher



No impact outside

Containment integrity maintained

Long time corium control

The EPR safety approach drastically limits the long-term impact on the environment

AREVA

Post-Fukushima Safety authorities assessments on EPR™ Design

▶ **Stress tests performed in Europe following European directives highlighted the intrinsic Robustness of the EPR™ design:**

◆ In France, the National Authority ASN reported that “the enhanced design of [the EPR™ reactor] ensures already an improved robustness with respect to the severe accident” in its Complementary Safety Assessment (CSA)

◆ In Finland, STUK (Safety Authority) highlighted in its final report that “Earthquakes and flooding are included in the design to ensure safety functions to a high level of confidence

- 1- EPR Safety
- **2- Current EPR Projects**
- 3- “FOAK” Lessons Learned
- 4- EPR Licensing worldwide
- 5- Efficiency & Performance

AREVA

4 EPR reactor units under construction

Olkiluoto 3

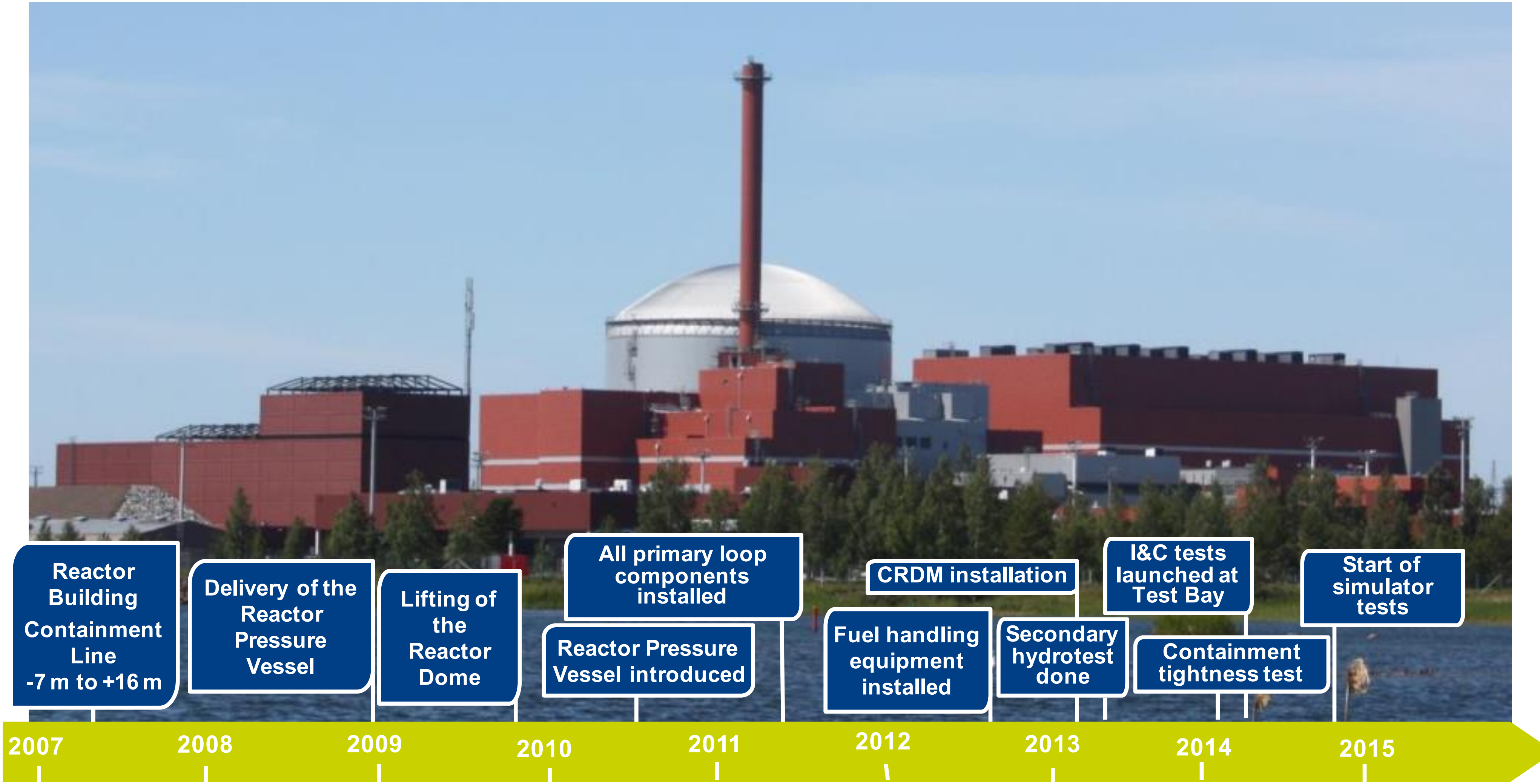
Taishan 1&2

Flamanville 3

Synergies based on series experience

AREVA

Olkiluoto 3 EPR project
Project Progress



AREVA

Olkiluoto 3 moving towards completion
3 major milestones reached in 2014

1. February 2014: complete success of the **Containment Tightness Tests**
2. April 2014: validation by STUK of the overall **I&C architecture** after 4 years of exchanges
3. **Start of the I&C tests** at AREVA's test bay in Germany (as required by STUK)
   - April 214: TXP tests (process)
   - July 2014: TXS tests (safety platform)

AREVA

Olkiluoto 3
Progress update

Key Facts

- August 2014: delivery of updated schedule to TVO
  - Updated schedule possible following the approval of the overall I&C architecture by STUK in April 2014
  - Mid-2016: construction completion
  - End 2018: start of commercial operation
- Major progress on I&C, currently driving the critical path
  - I&C process (TXP) and I&C safety (TXS) tests ongoing according to schedule at test bay in Germany
  - After test phase, I&C cabinets delivery at OL3 site scheduled for September 2015
  - Start of tests on 3 simulators in parallel in Finland, Germany and Canada
- Construction activities
  - I&C and power cabling activities ongoing
  - Working on remaining HVAC and piping activities
- Commissioning activities
  - Reactor containment tightness tested
  - HVAC systems commissioning ongoing
  - Preparation ongoing for start of systems commissioning

All critical path activities on track

Olkiluoto 3 moving towards completion
Successful Containment Tightness Tests (CTT)



February 2014

" You can be only happy about such result! " - TVO

"This cooperation has been very successful and everybody has put a lot of effort to carry out the CTT and result is fine " - STUK

AREVA

Olkiluoto 3 moving towards completion
I&C driving the project critical path

April 2014

Start of I&C tests: TXP (Process) platform

July 2014

Start of I&C tests: TXS (Safety) platform

AREVA

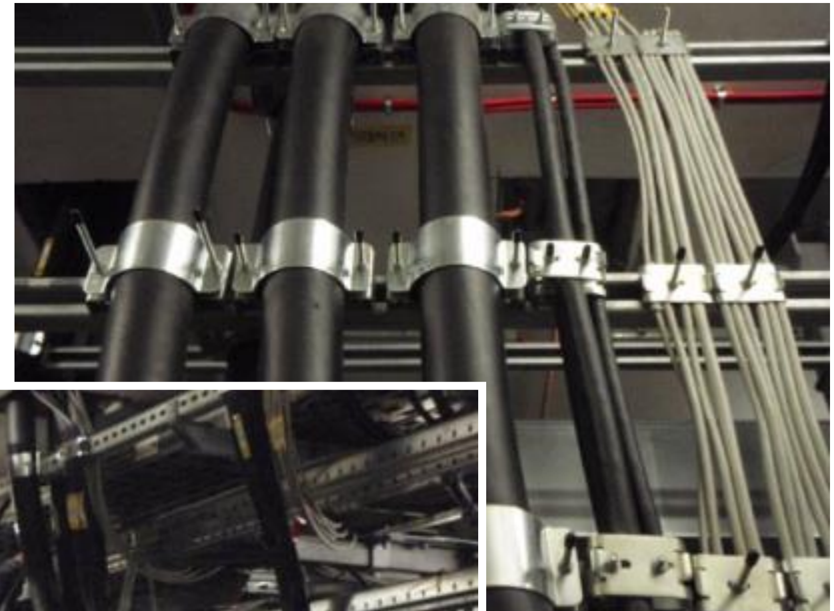
Olkiluoto 3 moving towards completion
Simulators testing

October 2014

Start of tests

AREVA

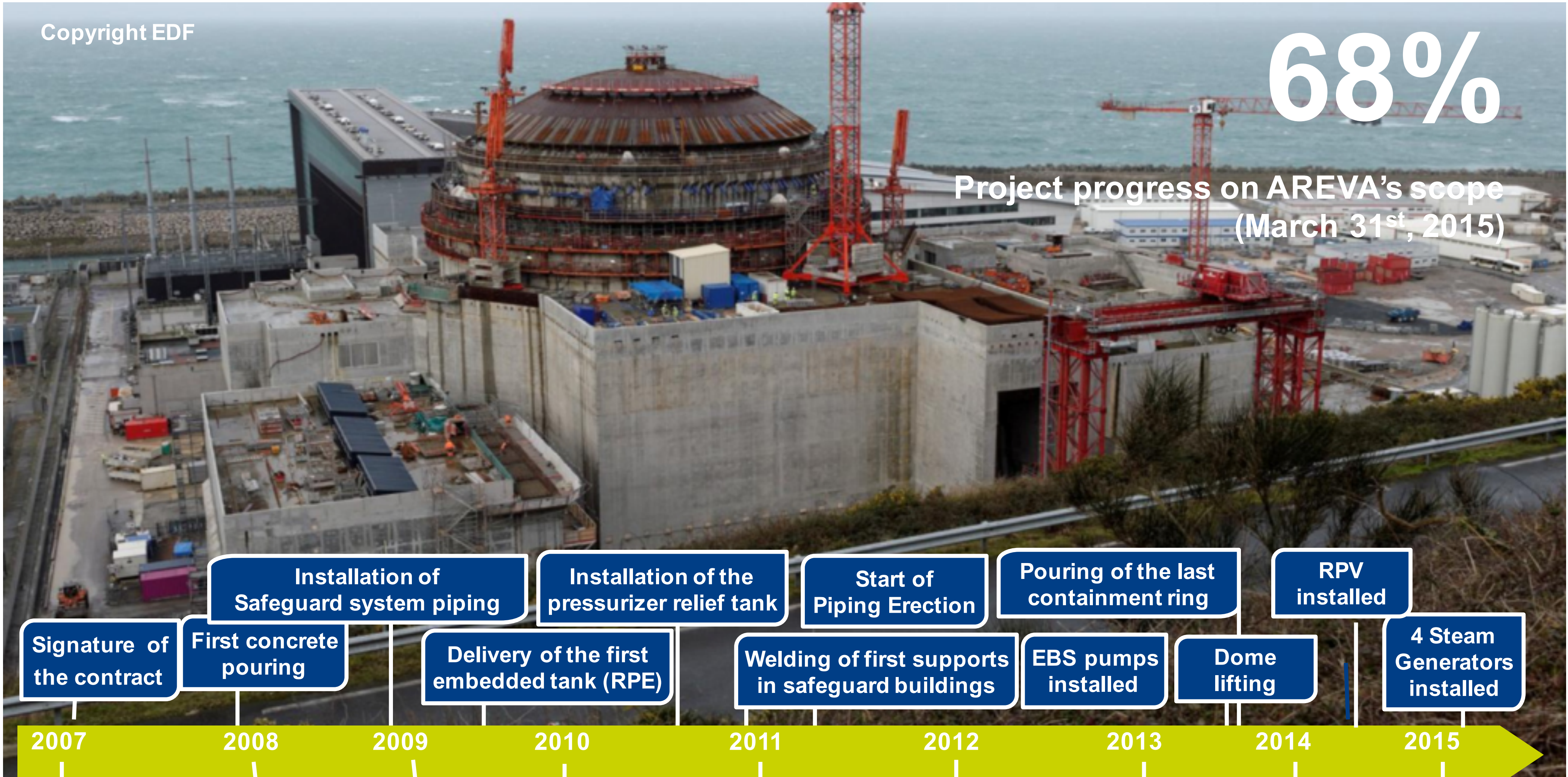
Olkiluoto 3 moving towards completion
Ongoing cabling works



January 2015

AREVA

Flamanville 3
Project progress



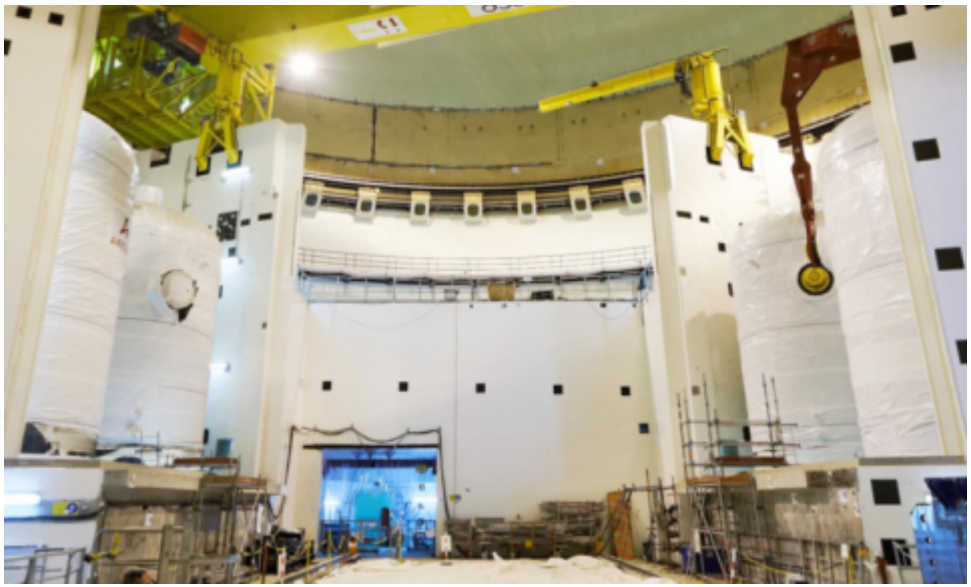
AREVA

Th
is

Flamanville 3
Progress update

Key Facts

- AREVA scope
  - Engineering: 88%
  - Procurement: 88%
  - Primary loop equipment:
    - All equipment delivered on site & introduced
    - All steam generators installed, welding in progress
  - Remaining primary equipment (such as CRDM, RPVI): delivery planned between July and Nov. 2015
  - I&C: installation of operational I&C and safety I&C cabinets on site ongoing
  - Licensing:
    - Operating License Application file preparation completed (Oct. 2014)
    - Licensing activities ongoing
- Outside AREVA scope
  - >95% progress of civil work
  - RB cable pre-stressing under finalization (planned May 2015)



March 2015

AREVA

Flamanville 3
Primary loop components delivery and installation

January 2014

Reactor Pressure Vessel
installation in the Reactor Building

AREVA

Flamanville 3

First commissioning tests from the control room

AREVA

Flamanville 3
Systems delivery and installation

June 2014
Primary loop welding

July 2014
Cold leg introduction

AREVA

Flamanville 3

Systems delivery and installation

August 2014, Steam Generators introduction in the reactor building

AREVA

Flamanville 3
Systems delivery and installation

August 2014

Steam Generators introduction in the reactor building

AREVA

Flamanville 3
Systems delivery and installation

November 2014

Installation of the pressurizer in the reactor building

Flamanville 3
Systems delivery and installation

March 2015

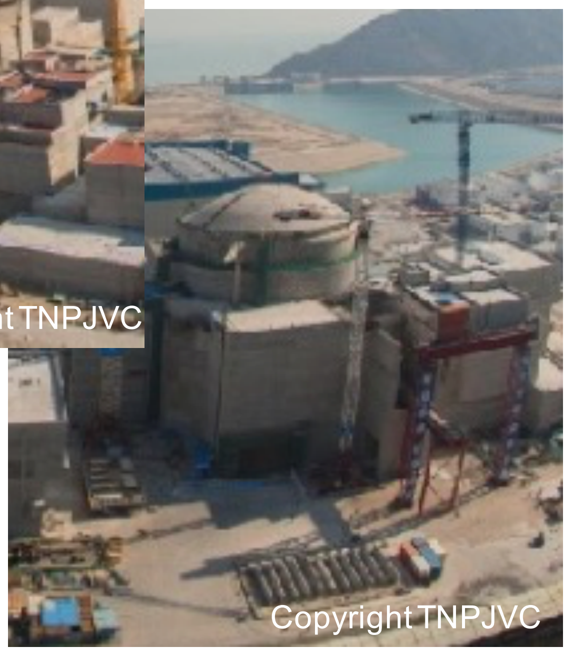
The 4 steam generators have been introduced in the reactor building

AREVA

Taishan 1&2 EPR Project
Project progress

AREVA

Taishan 1 & 2
Progress update



Key Facts

- AREVA scope
  - Procurement: 97%
  - Engineering: 98%
- Progress
  - Unit 1:
    - All primary heavy components installed, primary pumps installed with their motors, CRDM installation in progress
    - Reactor and fuel pools completed and hydrotested
    - Commissioning phase started end 2014
    - Main control room ready for commissioning
  - Unit 2:
    - Polar Crane commissioned
    - Heavy components manufactured and hydrotested
- Main activities in 2015
  - HVAC and piping erection completed
  - Electrical cable pulling in progress
  - Commissioning activities
  - Preparation of Cold Functional Tests

Note: all percentages (%) in terms of € value

AREVA

Taishan 1

Completion: major equipment installation

June 2014

Control Room Simulator installed at Taishan

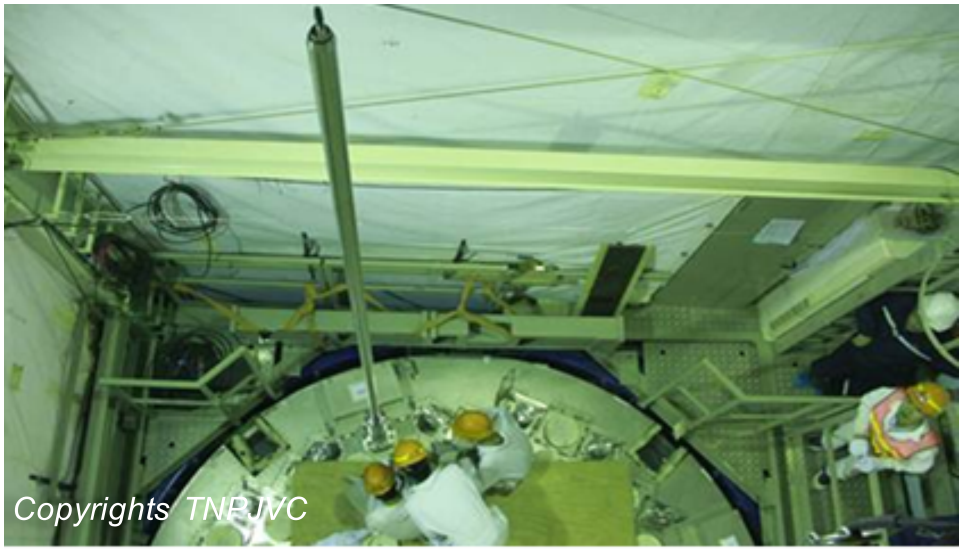
Th is

Taishan 1
I&C delivery

June 2014 – Delivery of Operational I&C

Beginning 2015 – Delivery of Safety I&C

Taishan 1
Achievements & Progress



January 14, 2015

Installation of CRDM (Control Rod Drive Mechanism) Pressure Housing started

January 12, 2015

Main Steam Isolation Valves introduced

AREVA

Taishan 1
EM4 pipes installation ongoing

EM4 Piping

VVP/ARE Pipe

Taishan 1
Commissioning Activities

November 2014

Switchboards Back Energizing performed

December 2014

SEC pumps (Essential Service Water System)

- One SEC pump tested with success
- Others are in progress

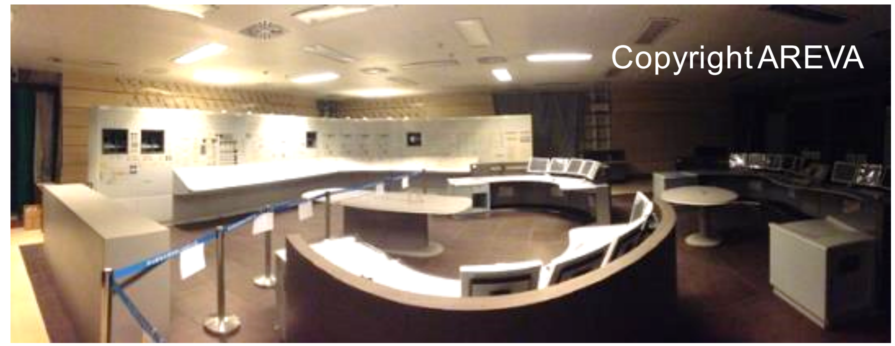
AREVA

Taishan 1
Engineering Simulator is operational

January 2015

Engineering Simulator operational

Taishan 1
Main Control Room ready for commissioning



April 2015

Main Control Room
completed

- 1- EPR Safety
- 2- Current EPR Projects
- 3- “FOAK” Lessons Learned
- 4- EPR Licensing worldwide
- 5- Efficiency & Performance

EPR™ reactor lessons learned process achievements

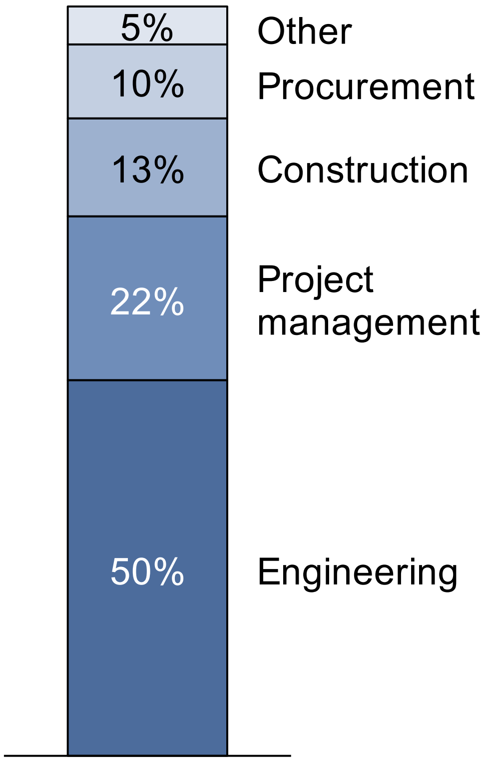
		Evolution between OL3 and Taishan
Engineering	Number of engineering hours on the Nuclear Steam Supply System scope	- 60 %
Construction	Duration of construction (from 1st concrete to dome installation)	- 50 %
Procurement	Average procurement time (reliability of procurement planning)	- 65 %
Total	Total construction time (from 1st concrete to 1st criticity)	- 40 %

AREVA

Synergies based on series experience
Knowledge management

Lessons learned process

- A systematic process…
  - There are more than 2200 Experience Feedbacks in the data base coming from current projects and our work on currently operating plants
- … well established in the company
  - Around 1 Experience feedback per day has been captured
- This unique project delivery experience has allowed AREVA to improve on all aspects of project execution
  - Project management and organization
  - Engineering
  - Procurement
  - Construction

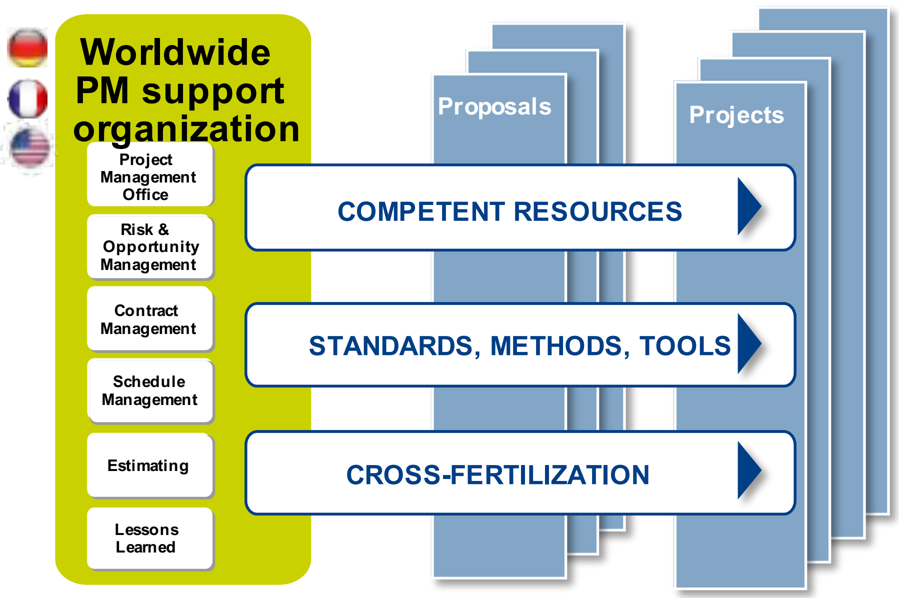


Experience feedback by discipline

AREVA

Synergies based on series experience
Project organization

Generic organization leveraging experienced teams



Experienced teams

For the Taishan projects:

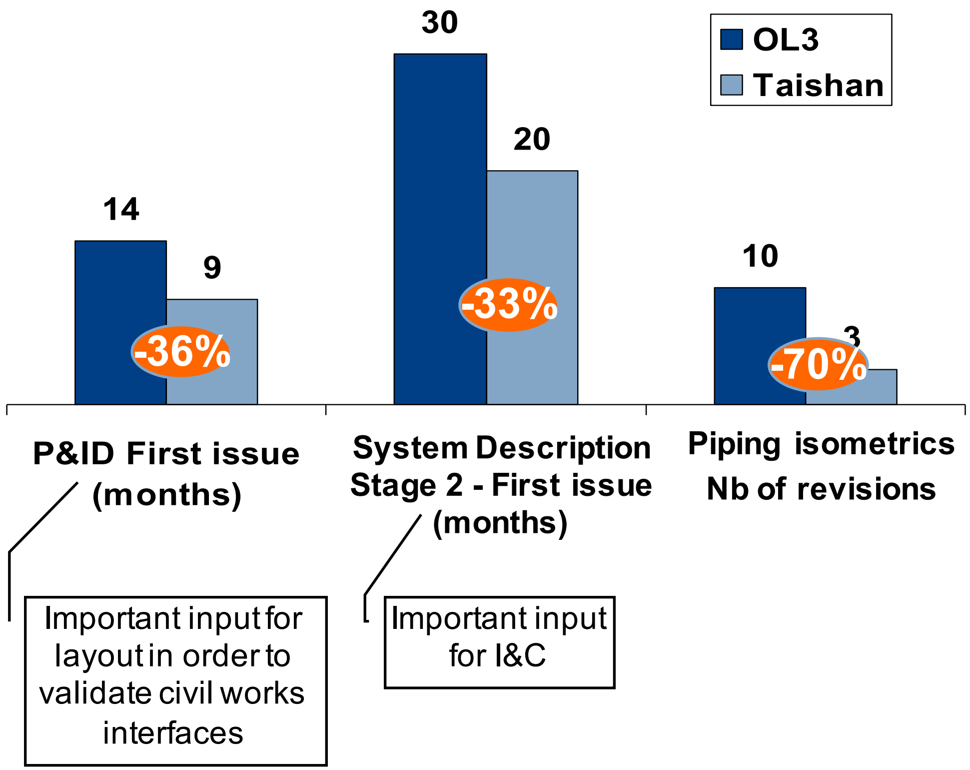
- 50% Management Directors & Managers,
- 50% Engineering staff,
- 90% Procurement workforce,

have worked on the OL3 or FA3 projects

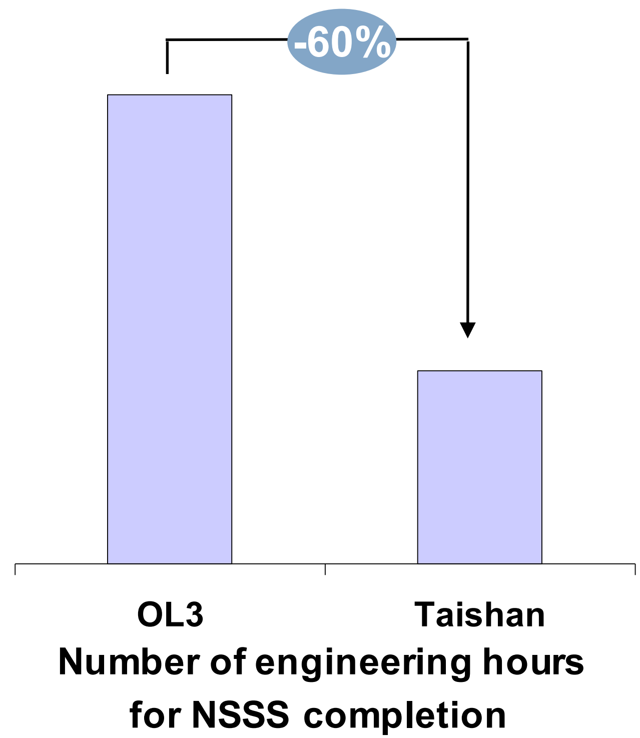
Project support by a worldwide organization

Synergies based on series experience
Engineering

Standardization of early engineering activities



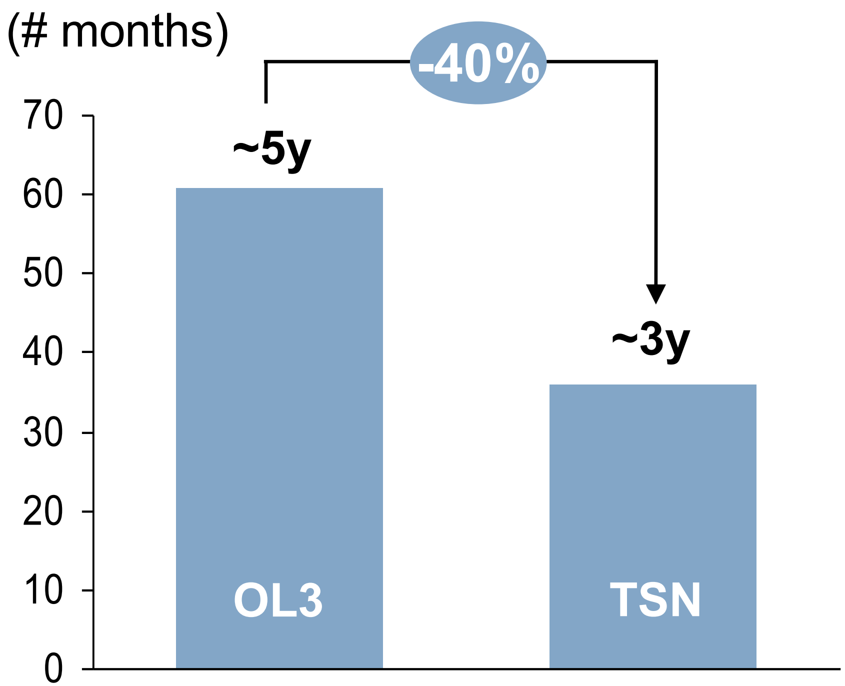
NSSS engineering standardized and streamlined



AREVA

Synergies based on series experience
Supply chain and manufacturing

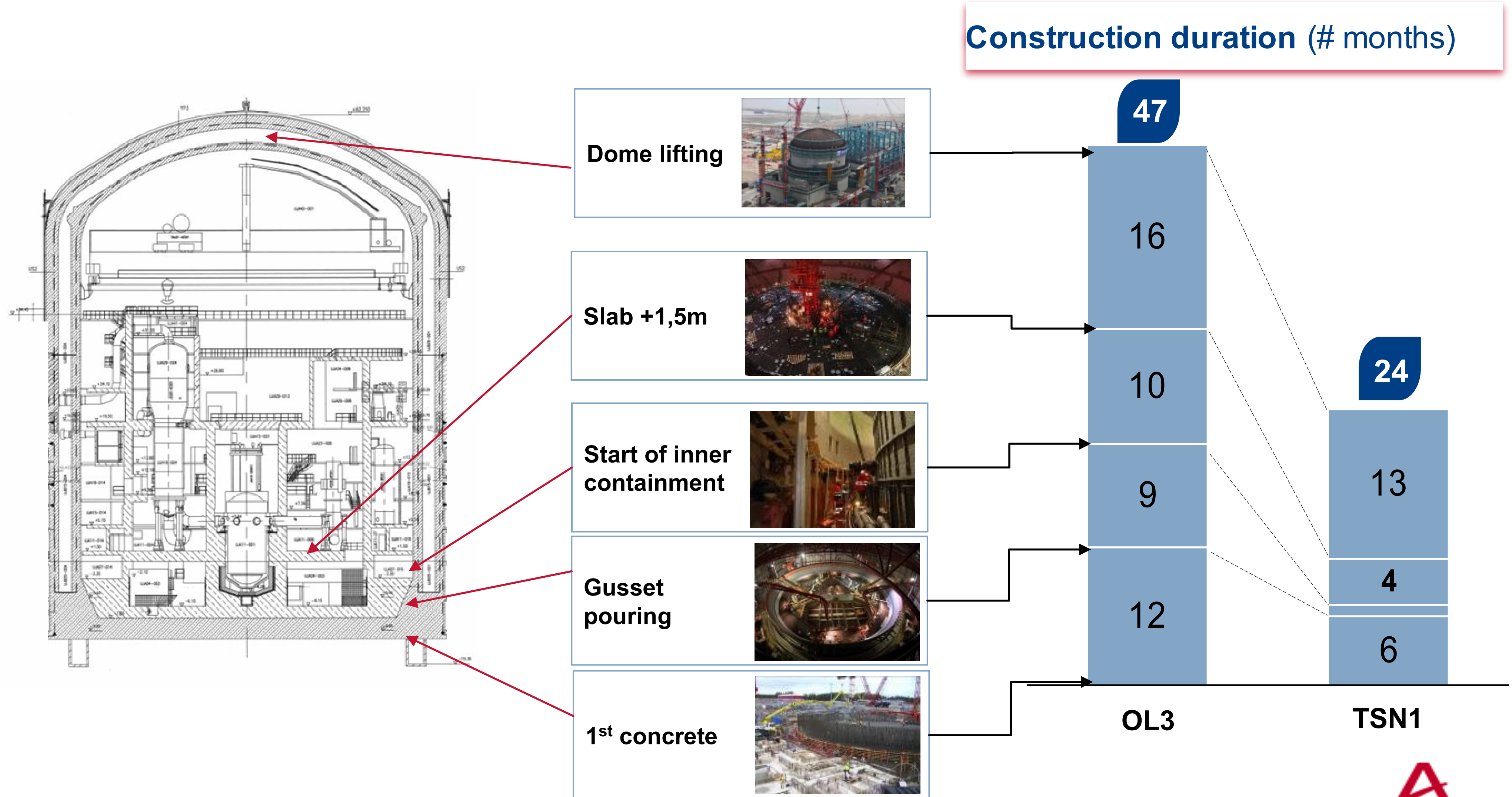
SG manufacturing duration



April 2012

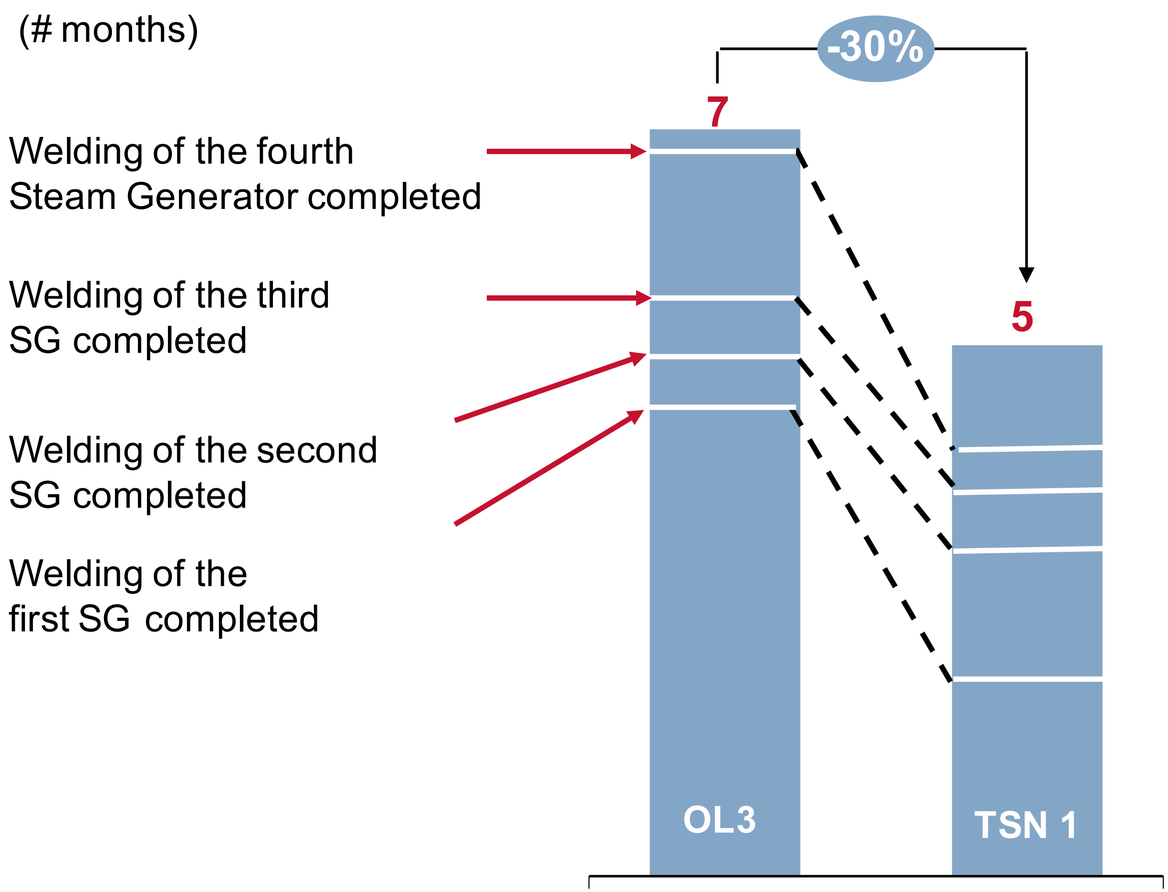
First two steam generators delivered on Taishan site

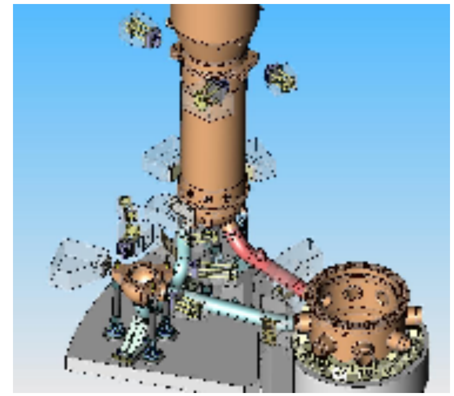
Synergies based on series experience
Construction

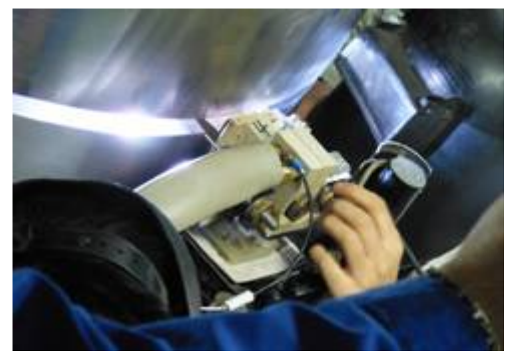


Synergies based on series experience
Installation

Duration of the primary loop welding







Welding of SG1, Taishan

AREVA

The EPR reactor benefits from synergies based on series experience. This experience brought AREVA key lessons learned in engineering, supply chain and construction to give you increased certainty for projects going forward.

AREVA

forward-looking energy

- 1- EPR Safety
- 2- Current EPR Projects
- 3- “FOAK” Lessons Learned
- **4- EPR Licensing worldwide**
- 5- Efficiency & Performance

The value of Experience: Licensing
Reviewed by reference Safety Authorities

- **The EPR™ reactor**
  - **Construction license granted by Finnish, French and Chinese Safety Authorities**
  - **Final Design Acceptance confirmation issued by the ONR in the UK in Dec '12**
  - **Design Certification by US NRC expected by 2015**
- **The only Gen3+ design submitted to the post-Fukushima European Safety checks**
- **The EPR™ Reactor fully complies with WENRA* objectives for New Power Reactors and is ready to comply with post-Fukushima requirements**
- **This unique breadth and depth of design review strongly mitigates the licensing risk related to nuclear new build**

**network of Chief Regulators of EU countries*

2005 STUK

2007 asn AUTORITÉ DE SÛRETÉ NUCLÉAIRE

2009 国家核安全局 **NNSA**

2012 **ONR/** HSE Health & Safety Executive

2015 U.S. Nuclear Regulatory Commission

AREVA

- 1- EPR Safety
- 2- Current EPR Projects
- 3- “FOAK” Lessons Learned
- 4- EPR Licensing worldwide
- **5- Efficiency & Performance**

AREVA

The EPR™ Operational performance

- Large core & low power density
- Heavy neutron reflector
- Improved total plant net efficiency

→ **Low fuel cost:** Up to 15% less than other Gen3/3+ reactors

- High output and availability

→ **Low O&M costs:** Up to 20% less than other Gen3/3+ reactors

→ **Best-in-class OPEX**

- Accessible containment
- Short cool down time
- Online maintenance of Safety trains

→ **Optimization of outages:** World class <11 days for refueling only outage

→ <1 unplanned reactor trip/year

→ **design target availability 92% over 60 year design lifetime**

The EPR™ reactor offers unparalleled operational performance with no compromise on safety

AREVA

Operations: best-in class OPEX

- **Fuel costs**
  - Large core (less neutron lost) & low power density: 241 fuel assemblies
  - Heavy neutron reflector: reduced neutron leakage enabling 2-3% fuel savings (and reducing RPV irradiation)
  - Improved total plant efficiency: high steam pressure thanks to upgraded steam generators
  - Fuel costs up to 15% below those of other Gen3/3+ reactors
- **O&M costs**
  - High output and availability of a single unit reduce O&M cost/MWh
  - Proven evolutionary components based on hundreds of years of reactor operations: large data-base to optimize preventive maintenance
  - O&M costs/MWh up to 20% lower than other Gen3/3+ reactors

EPR™ Reactor operational performance maximizes asset value

AREVA

Operations: High Availability

Outage duration reduction:

- Preventive maintenance on safety trains
- Large set-down area to prepare outage work
- Fast cool-down of the core

➔ Short outages:

Short outages:	Refuelling only outage	<11 days
	Normal refuelling outage	<16 days
	Ten-year outage	<40 days

High reliability:

- Proven evolutionary components based on hundreds of years of reactor operations: improved reliability
- Unscheduled unavailability rate lower than 5 days / year (3 days / year for NI) : 1.4 % / r.y
- Capability to cope with various grid failure situations and loss of equipment without Reactor Trip

➔ <1 unplanned reactor trip/year

EPR™ Reactor design target availability above 92 %

AREVA

Operations: High Availability

- Approved by 4 Safety Authorities, the EPR reactor is the reference for safety
  - Strong resistance to extreme hazards, European stress tests passed
- Designed for competitiveness, with a high power output and innovative features :
  - Up to 20% savings on operation and maintenance costs
  - Up to 15% savings on fuel costs
  - Optimized site and land use
- AREVA is capturing a unique project delivery experience and best practices from past and on-going projects, for the benefit of customers' needs
- Safety as first priority, with stringent objectives
- Leverage construction experience and capabilities with in-house expertise, proven construction methods and continuous improvements