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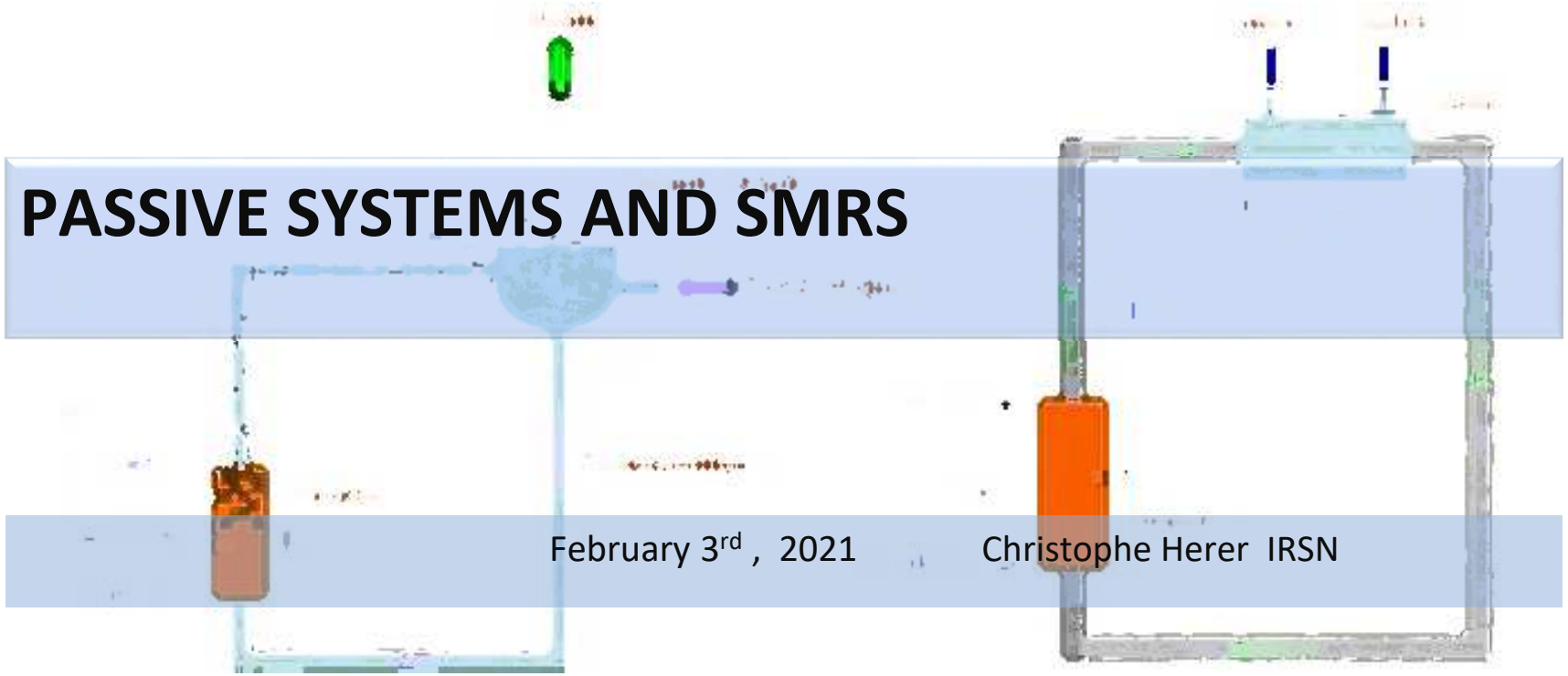

PASSIVE SYSTEMS AND SMRS

February 3rd , 2021

Christophe Herer IRSN

Contents

- Passive systems and SMRs
- Typical applications
- Safety Analyses
- R&D
- Conclusion

Few words about IRSN

Technical support organization for the Nuclear Safety Authority

Nuclear Operators

EDF cea AREVA NEUTRONS FOR SOCIETY

framatome

Stakeholders (CLI, etc..)

Nuclear Safety Authority

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Expertise - Research

IRSN

only PWR

one operator EDF
standardized fleet PWR
(900 MWe, 1300 MWe, 1450 MWe)

- seaside
- estuary side
- riverside with cooling towers

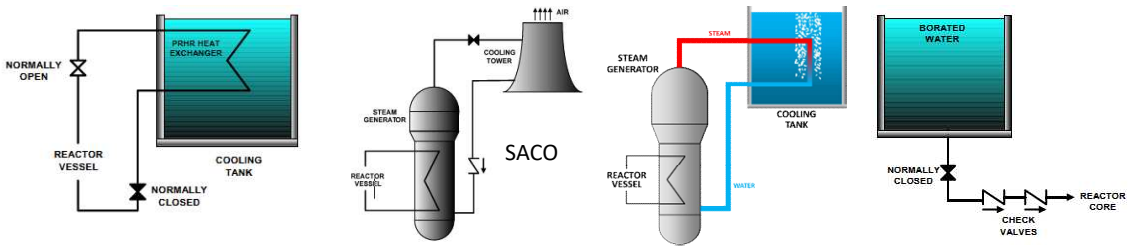
Research reactors:
operated by CEA (Saclay & Cadarache)
and by ILL (Grenoble)

56 Reactors in Operation on 18 sites 1977-2021	PWR series		
	900 MWe	1300 MWe	1450 MWe
Total	32	20	4
	56		

Passive systems

- IAEA Definition
  - TECDOC 626 (AIEA, 1991)
    - "The concepts of active and passive **safety** describe the manner in which engineered safety systems (…) are distinguished from each other by determining whether ***there exists any reliance on external*** mechanical and/or electrical ***power***, signals or forces. The absence of such reliance in passive safety means that the **reliance is instead placed on natural laws, properties of materials and internally stored energy**."
    - Passive Component : a component which does not need any external input to operate
    - Passive system : Either a system which is composed entirely of passive components and structures or a system which uses active component *in a very limited way* to initiate subsequent passive operation

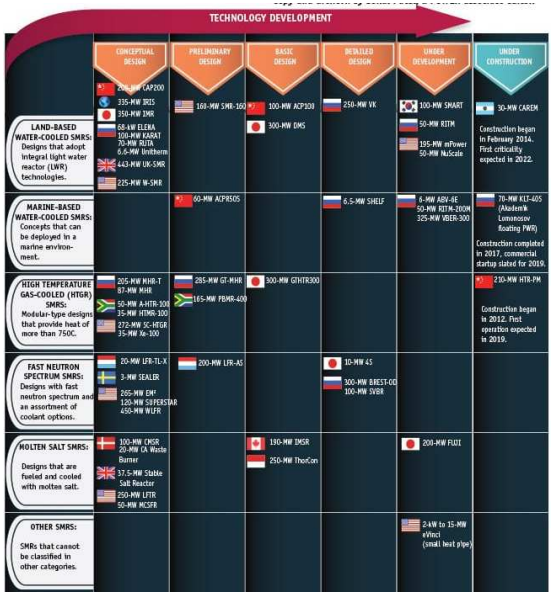
- IAEA Examples
  - TECDOC 1624 (AIEA, 2009)
    - Passive Residual Heat Removal PRHR
    - Safety Condenser SACO
    - Elevated gravity drain tanks
    - …..



SMRs

- SMR : as introduced by IAEA « Small and Medium sized Reactors »
  - IAEA nomenclature
    - Small reactor : < 1000 MWth
      equivalent electric power < 300 MWe,
    - Medium reactor : power between 300 and 700 MWe
  - Initially AP600; VVER 640 are considered as SMR

- Several types of SMRs (Light Water, Gas-cooled, Liquid Metal)
  - We focus here on **SMRs based on Pressurized Water Coolant**



Copy and artwork by Sonal Patel, a POWER associate editor (@sonalcpatel, @POWERmagazine)
https://www.powermag.com/the-big-picture-small-modular-reactors/

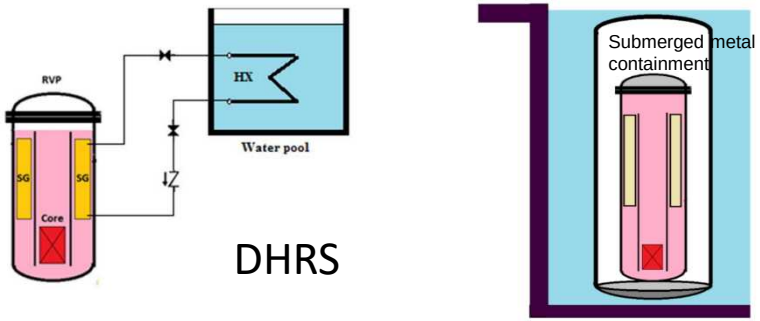
- SMR as “Modular”
  - **Manufacturing and testing are carried out in the factory**, guaranteeing better construction quality, shorter assembly times on site and easier decommissioning. The installations of nuclear and conventional sub-assemblies are designed and **manufactured in a modular way**, each module being transportable by land or sea for assembly on site. This approach is broadly applied in the field of naval construction. The modular approach to the manufacturing process also involves civil engineering.

Technology Unveiled March 2015 (EDF) https://www.edf.fr/sites/default/files/Lot%203/CHERCHEURS/Publications/small-modular-reactor.pdf

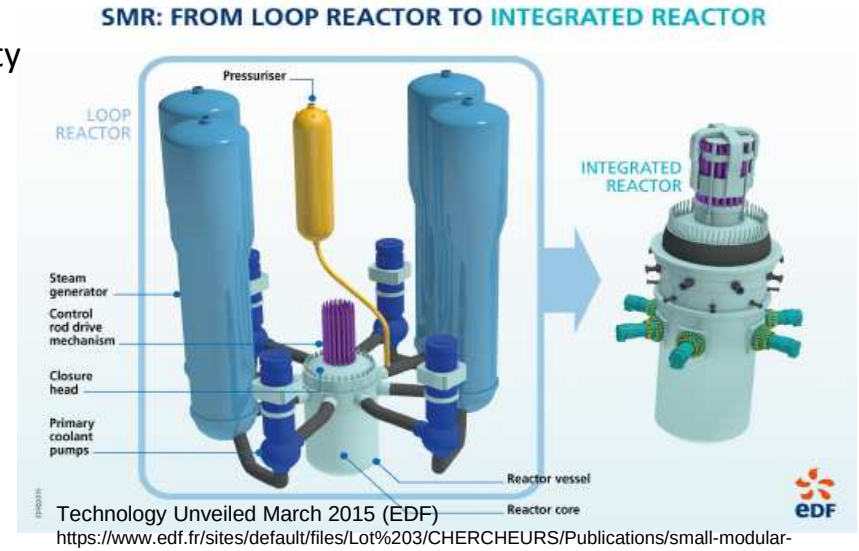
SMRs

- SMR as Integrated reactor
  - The reactor's integrated architecture benefits from its modularity and offers advantages in terms of safety. The reactor vessel includes the core, the steam generators, the pressuriser and the primary coolant pumps, thus removing the need for primary coolant loops.

- SMR with passive systems
  - In operation (natural circulation without pump)
  - As safety systems



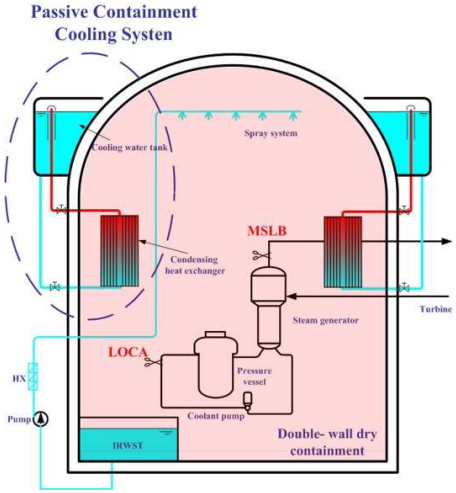
Design Safety Considerations for Water Cooled Small Modular Reactors Incorporating Lessons Learned from the Fukushima Daiichi Accident IAEA-TECDOC-1785



Technology Unveiled March 2015 (EDF)
https://www.edf.fr/sites/default/files/Lot%203/CHERCHEURS/Publications/small-modular-reactor.pdf

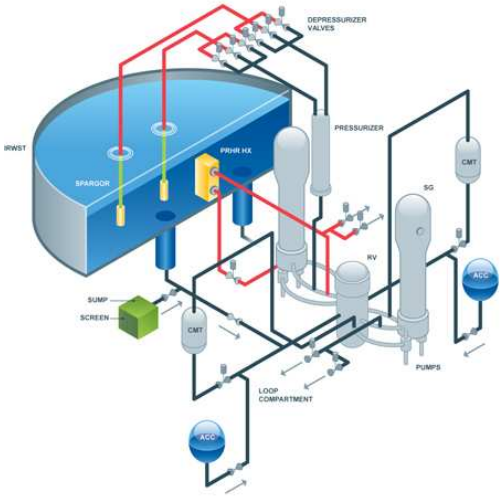
Typical applications

- Passive systems are not specific to SMRs
  - They are already integrated in operating NPP (AP1000, AES2006, HPR1000)

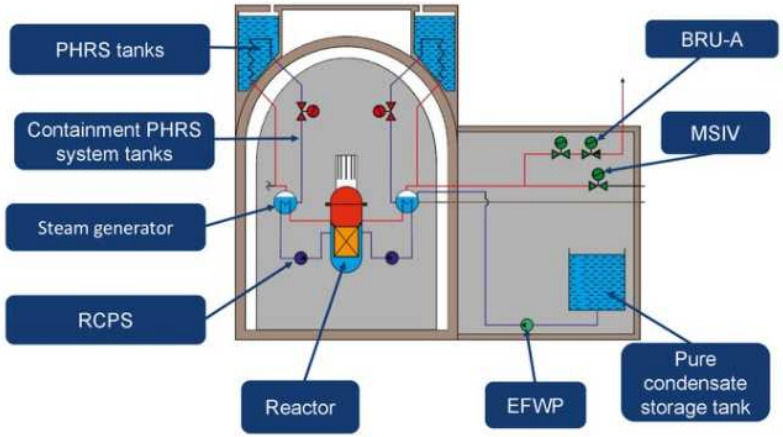


HPR 1000

X. Hou et al./Annals of Nuclear Energy 109 (2017)



AP 1000



AES 2006

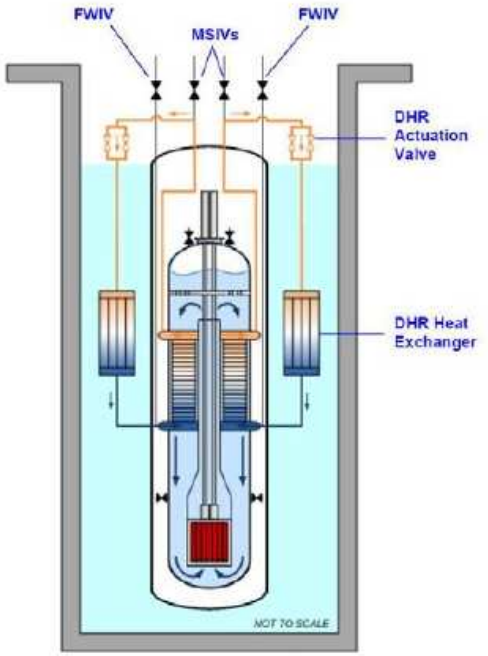
Fundamentals of Modern Russian-designed NPPs with VVER-1200

Typical applications

- Passive systems are not specific to SMRs
  - But indeed some of them rely heavily on them
    - Because Passive systems can be economically advantageous (compared to active components such as pumps)
    - Because passive systems may be more suitable for SMRs (require important driving forces e.g. flow rate)
  - They are indeed integrated in SMRS (e. g. NUSCALE)

	CAREM25	IRIS	mPOWER	NuScale	RITM-200	SIR	SMART	W-SMR
	Argentina	International	USA	USA	Russian Federation	USA, UK	Republic of Korea	USA
	CNEA	Consortium	Babcock & Wilcox	NuScale Power	OKBM Afrikantov	Combustion Engineering	KAERI	Westinghouse
Power level (MWth)	100	1000	530	160	175	1000	330	800
Power level (MWe)	27	335	180	45	50	320	100	225
Primary circuit circulation	Natural	Forced	Forced	Natural	Forced	Forced	Forced	Forced
Fully internal pumps	n/a	Yes	No	n/a	No	No	No	No
Soluble boron-free core	Yes	No	Yes	No	Yes	Yes	No	No
Internal CRDMs	Hydraulic	Electromag.	Electro-Hydraulic	No	No	No	No	Electromag.
Safety systems	Passive	Passive	Passive	Passive	(*)	Passive	Active and passive	Passive
DHRS	Passive	Passive	Passive	Passive	(*)	Passive	Passive	Passive

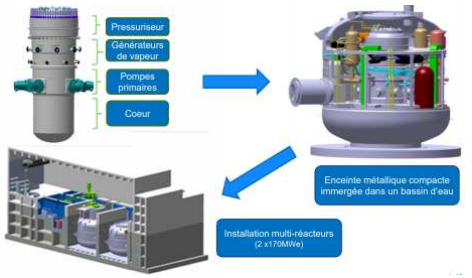
Safety of integral pressurized water reactors (iPWRs)
Chapter 8 of Handbook of Small Modular Nuclear Reactors: Second Edition (Woodhead Publishing)



Design Safety Considerations for Water Cooled Small Modular Reactors Incorporating Lessons Learned from the Fukushima Daiichi Accident
IAEA-TECDOC-1785

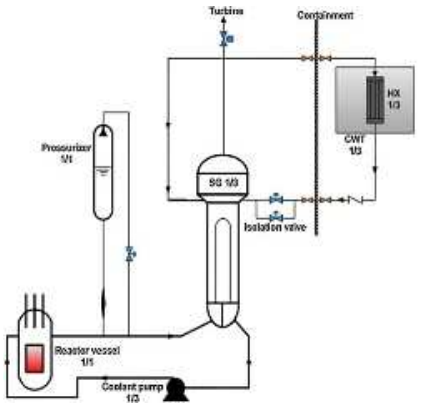
Typical applications

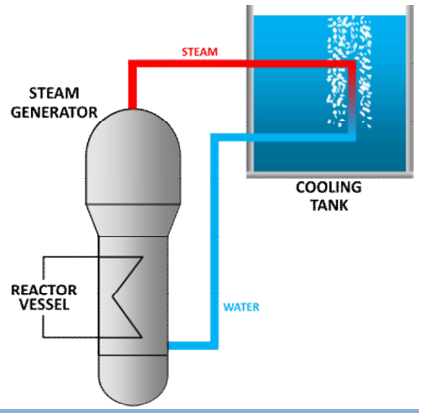
- IRSN and Passive Systems and SMRs
  - Passive systems are implemented in operating reactors in Europe (Russia, Belarus) and in project (Finland)
    - What the benefits and drawbacks of such systems ?
  - Need to require introduction of passive systems in future reactors constructed in France
    - In-depth analysis required (as active systems have proven high reliability)
  - Development of NUWARD in France (SMR proposed by TA, Naval Group, CEA & EDF)
    - A kind of “follow-up” of Flexblue



- IRSN has been more and more involved in the study of passive systems and SMRs
  - OECD activity
  - European H2020 projects (ELSMOR and PASTELS)
  - IAEA regulator’s forum
  - ATMEA and Flexblue Review

- IRSN focus on Decay Heat Removal or “Safety Condenser





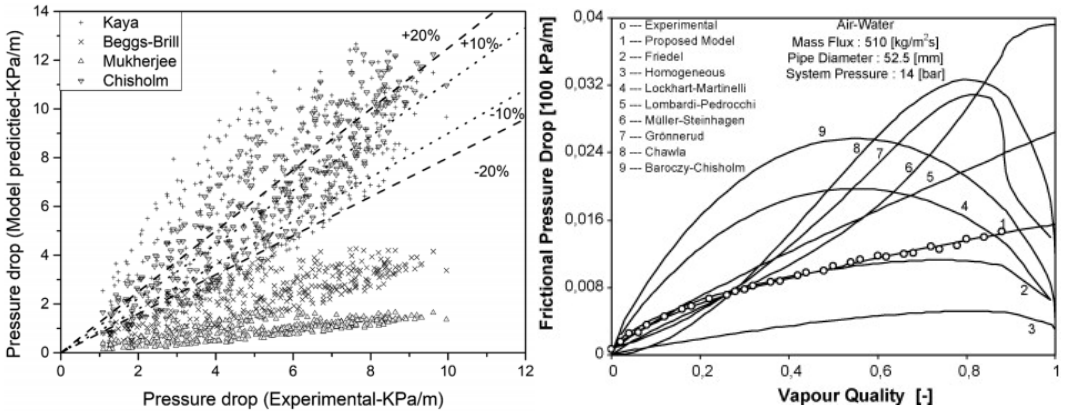
Safety Analyses

- Reliability
  - Including Human Action

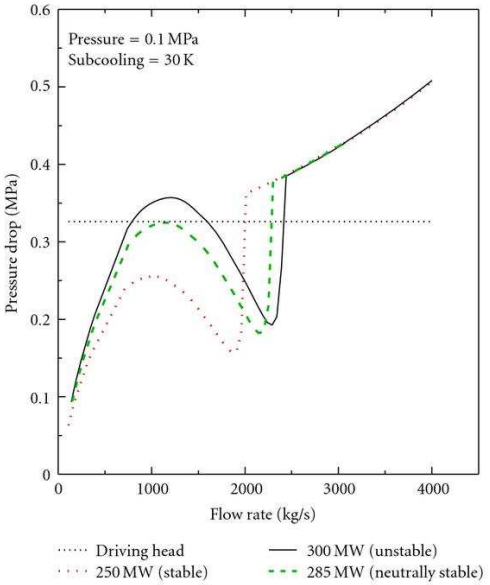
- Performance
  - Instabilities, Time lag
  - Models
    - Pressure drops, HX
  - Code qualification (coupled phenomena)
    - Instabilities
    - Parameter range
      – Low pressure, low power, low to very low velocities, …
    - Validation
      – SET, ITS , Component tests, Coupled Effect tests and scaling issues
    - 3D affect
    - ….
  - Uncertainties
  - Unexpected impact of some parameters
    - Leakages, fouling, non-condensable gas, unforeseen phenomena

Safety Analyses

- One example (Two-Phase Natural Circulation)
  - System operating point (flow rate) is at the intersection of the
    - Driving head (i.e. temperatures thus HX performance)
      - – " pump " performance curve : $\Delta\rho$ g H
      - – Heat transfer (tube immerged depends on several parameters)
    - Fluid flow system curve (i. e. Pressure loss vs flow rate)
      - – Large uncertainties



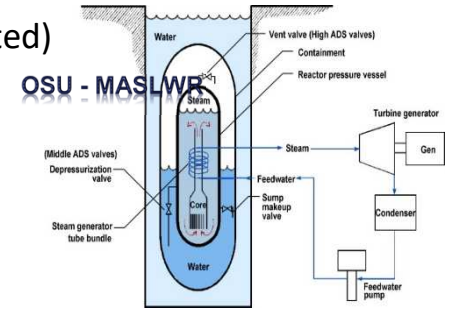
Nuclear Engineering and Design Volume 238, Issue 12, December 2008, Pages 3277-3284 Benbella A.Shannak "Frictional pressure drop of gas liquid two-phase flow in pipes"

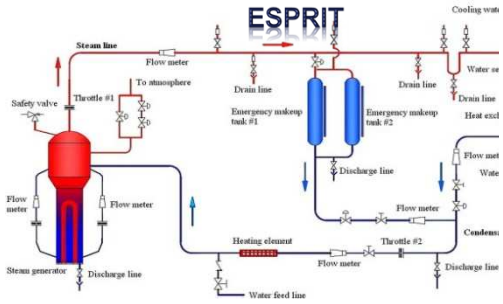


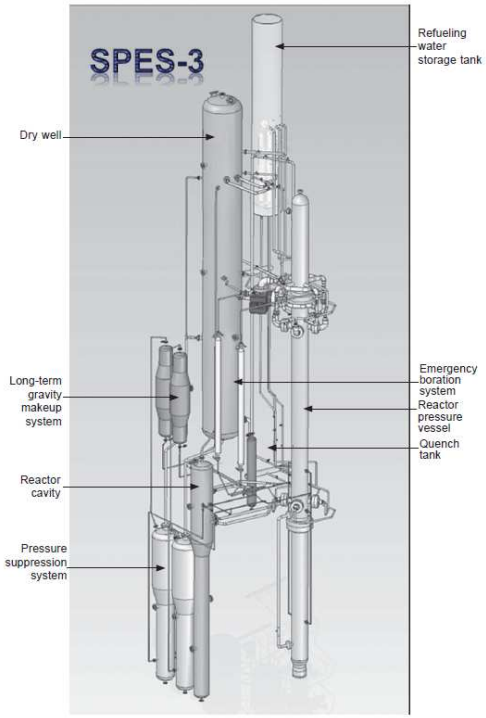
Science and Technology of Nuclear Installations / 2008 A. K. Nayak and P. K. Vijayan "Flow Instabilities in Boiling Two-Phase Natural Circulation Systems: A Review"

R&D and other studies

- Lot of R&D related to passive systems and SMRS
  - Done by designers (for AP1000, AES2006, HPR1000, Nuscale, SMART, …)
  - Done by universities, laboratories, …
- SMR regulators forum (IAEA)
- EC H2020 project ELSMOR (SMR) and PASTELS (Passive systems)
- OECD activity on passive systems
- WENRA (RHWG Report on Regulatory Aspects of Passive Systems)
- ETSON group (just started)

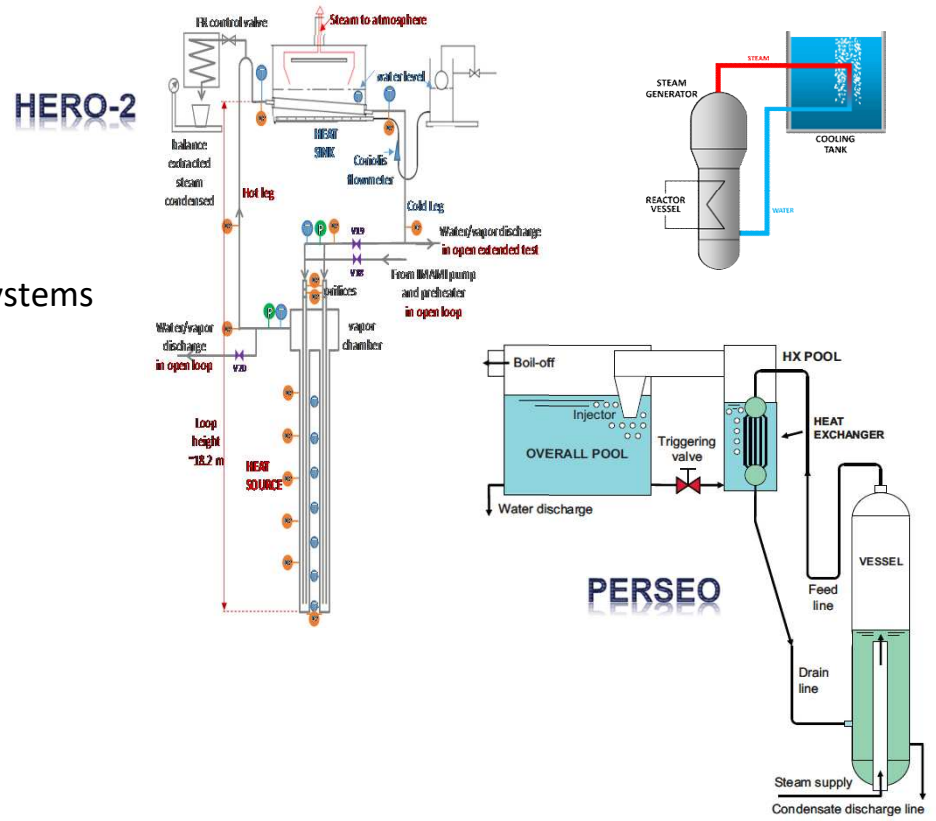






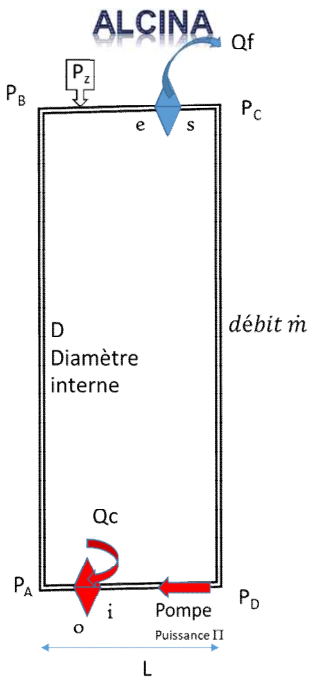
R&D at IRSN

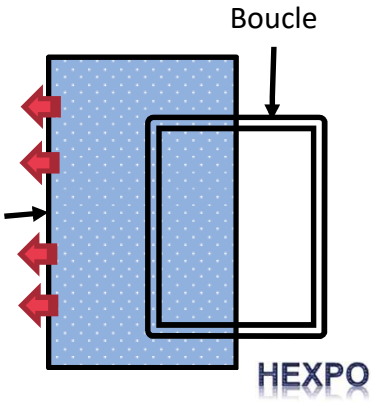
- Studies on “simple” experiments
  - HERO-2
  - PERSEO
- Numerical studies on SACO
- Studies on Reliability and Safety approaches for passive systems
- Participation in WENRA, IAEA SMR, OECD, H2020 projects
- Projects on new experimental support
  - Both for passive systems and SMRs
  - Not related to specific components or project
  - More “generic” oriented objectives
    - Model validation (and improvement)
    - Independent validation

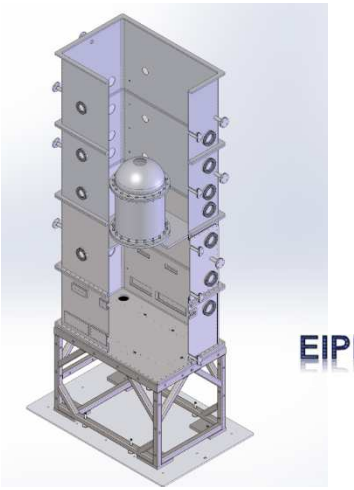


R&D : Projects at IRSN

- ALCINA test Loop
  - Closed Natural/Forced Circulation Loop (single and two phase)
    - With multiple pressure drop measurements and void measurements (in two phase configuration)
    - Several pipe diameters
    - Controlled Heat Exchangers
- HEXPO test Loop
  - Tube(s) immerged in a pool
    - With clear window for velocity measurements in pool
- EIPI test loop
  - Containment in a pool Internally heated
  - Measure of pressures and temperatures







Conclusions

- Passive systems are not virtual concepts
  - They are already integrated in operating NPP (AP1000, AES2006, HPR1000)
- Although no SMR are under construction, several designs are ready
- R&D, experimental support is significant
- However, these efforts has to be maintained and increased : everything is not “solved”
- IRSN, as a Technical Support Organization to French National Safety Authority, is involved in the technical review of these designs, although not currently installed in France
- Some independent experimental support is currently being considered at IRSN in addition to other activities