R&D activities underway and priority gaps and opportunities for climate resilience and preparedness

Nuclear power: OECD/NEA perspective

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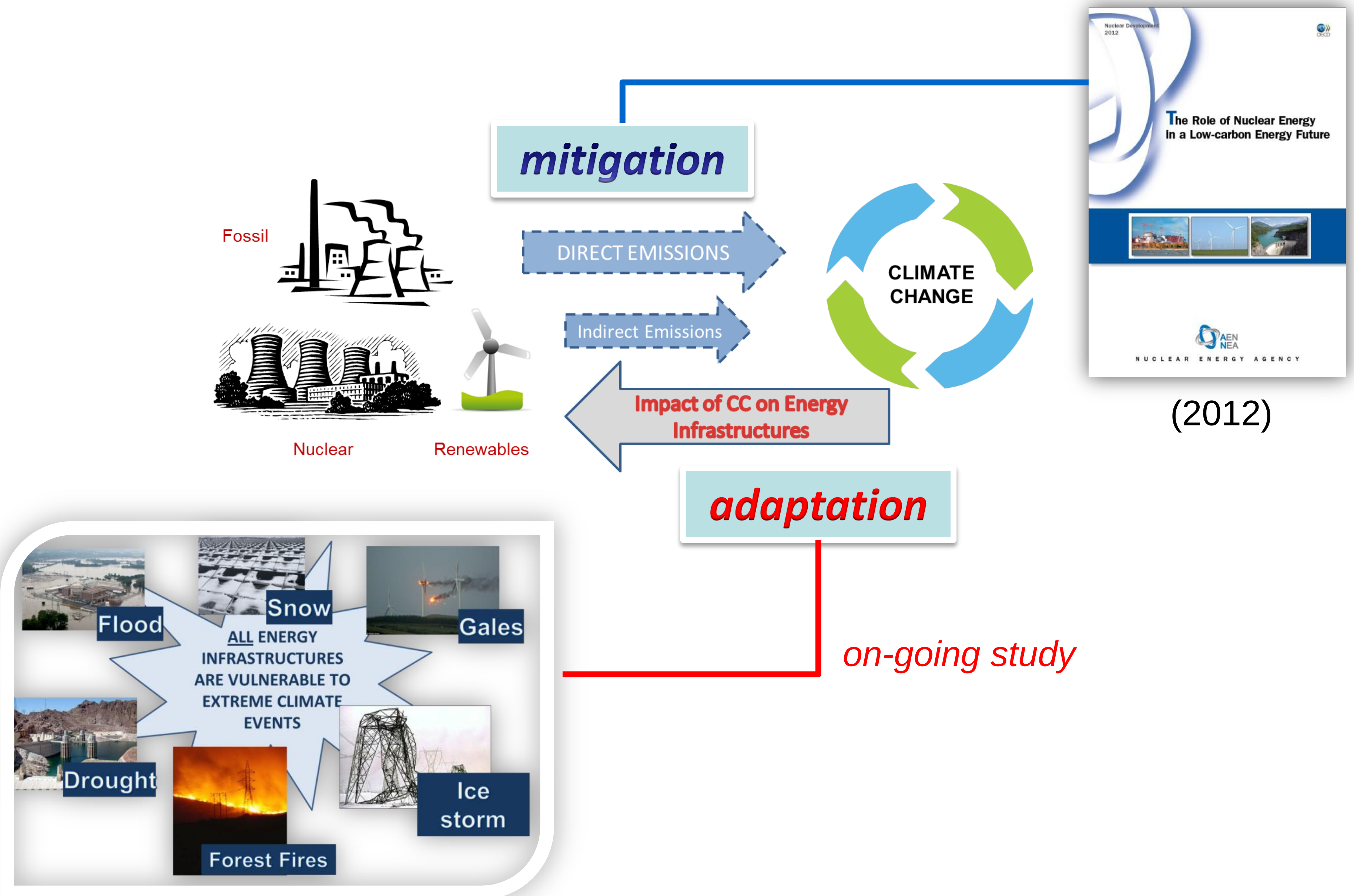
IEA CERT, Experts' Group on R&D Priority Setting & Evaluation

13-14 November 2013, Utrecht, the Netherlands

Nuclear Energy & CC: Mitigation - Adaptation



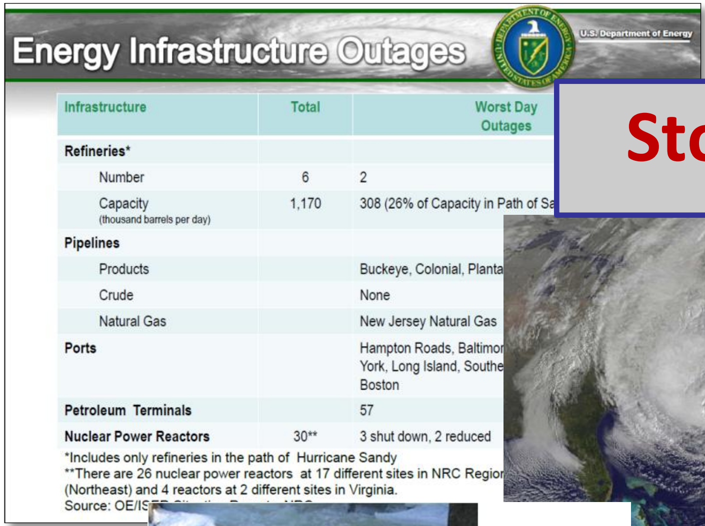
NEA Project (2013-2014)

Ad hoc Expert Group on CC: Assessment of the Vulnerability of NPPs and Cost of Adaptation *(Chair: J.Y. Caneill, EDF, France)*

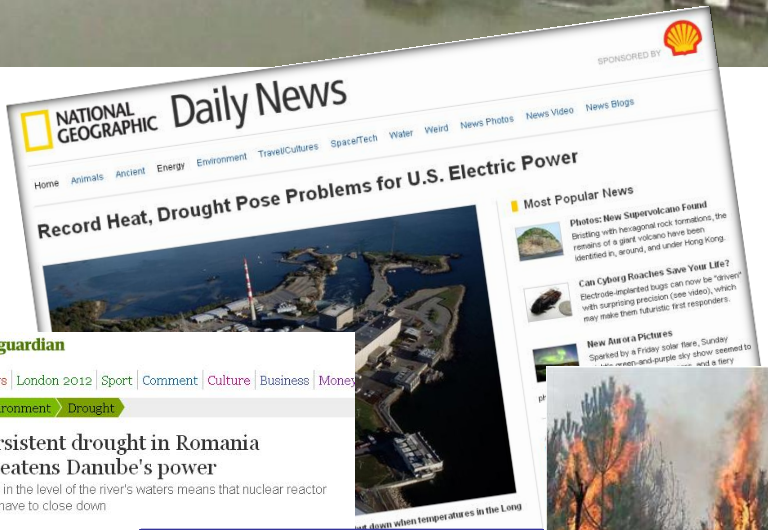
- 9 NEA countries: Austria, Canada, Czech Republic, Finland, France, Germany, Korea, Spain, US + IAEA, EC, IEA, OECD/ENV + consultation with industry
  - Experts from research and academic institutions, technical safety organisations, industry as well as international organisations.
  - Expertise in **nuclear safety and risk assessment, meteorology, climate change, sustainable energy systems, nuclear technology and economics**.
- Cost impact of CC (and in particular **extreme weather events - EWE**) on operation of NPPs and cost of adaptation measures: **"cost of inaction vs. adaptation cost"**
- Impact of extreme weather events on NPP operation & safety (<u>case studies</u>):
  - Canada: ice storm (transmission system), cooling from Great Lakes
  - Czech Republic: storms, extreme winds
  - France: heat wave/drought, floods
  - Spain: drought
  - US: floods, heat wave, storms
- Energy-Water nexus: cooling issues, technologies
- Regulations & policies (environment and safety)
- Security of energy supply aspects
- Recommendations to policy-makers (<u>including R&D aspects</u>)

Examples of EWE impacts on NPP

Floods

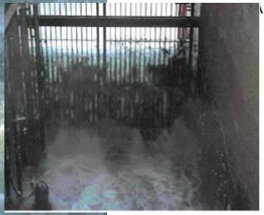


Storms



Drought / heat wave

Forest fires



Frazil ice

Ice storms

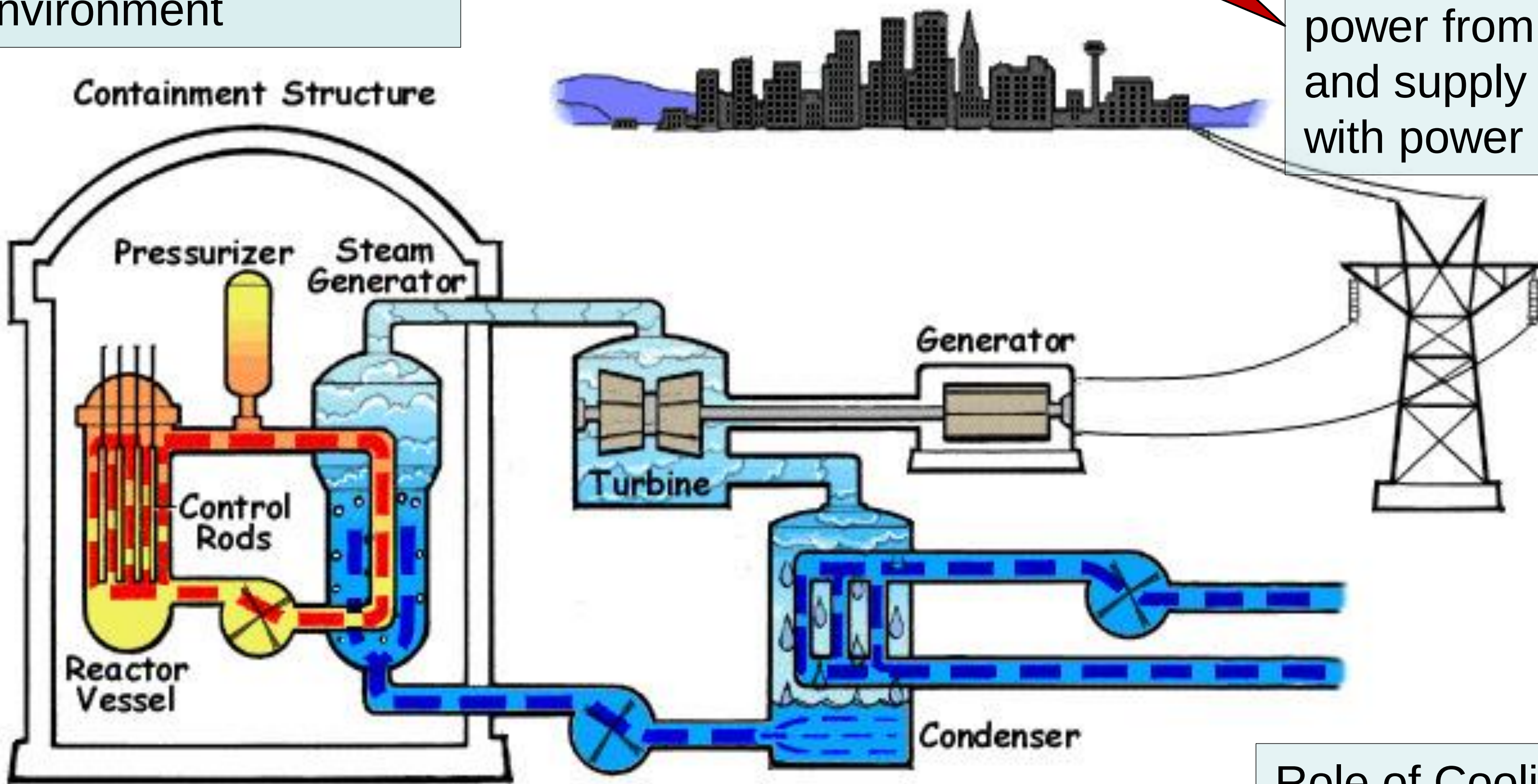
How can EWE affect a NPP?

<u>Role of containment:</u> ultimate barrier between reactor and environment

Floods, heat wave

Storms (wind, debris), ice storms, forest fires, heat wave

<u>Role of grid</u>: take power from NPP and supply NPP with power



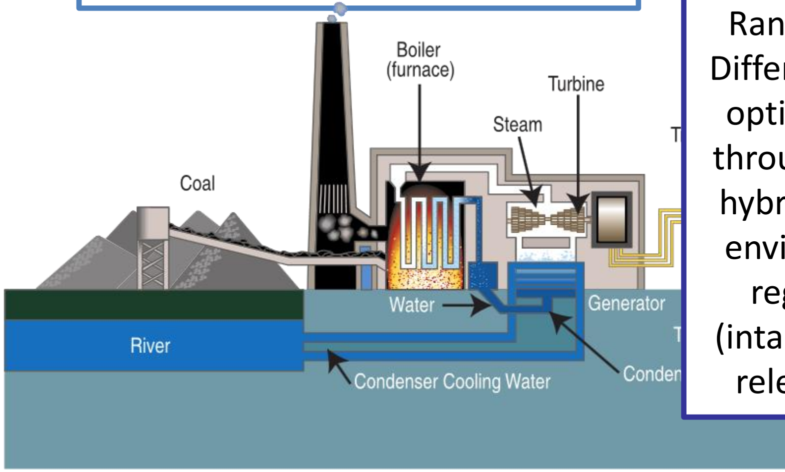
<u>Role of Cooling water</u>: cool condenser & remove decay heat

Storms (debris), heavy rain, floods, frazil ice, heat wave, drought, algae, …

Cooling for thermo-electric power plants

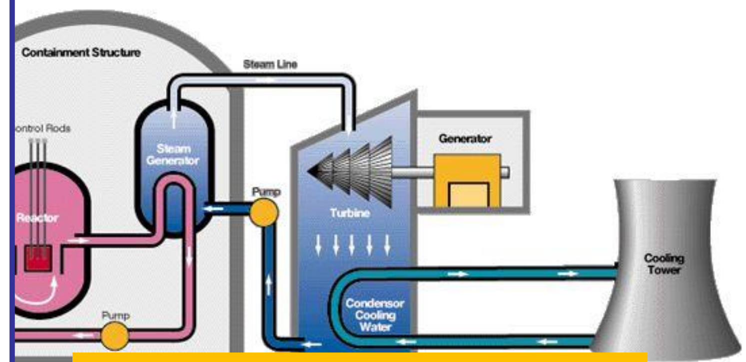
NORMAL OPERATION

Fossil



Same issues:
Rankine cycle, Different cooling options (once-through, closed, hybrid…), same environmental regulations (intake, thermal releases), etc

Nuclear

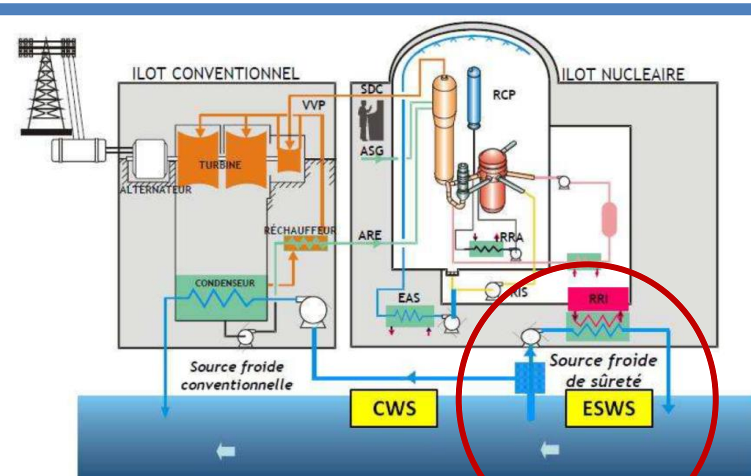


Circulating Water System (CWS)

THERMAL EFFICIENCY

ACCIDENTAL CONDITIONS

Shut down → no fuel → no residual heat

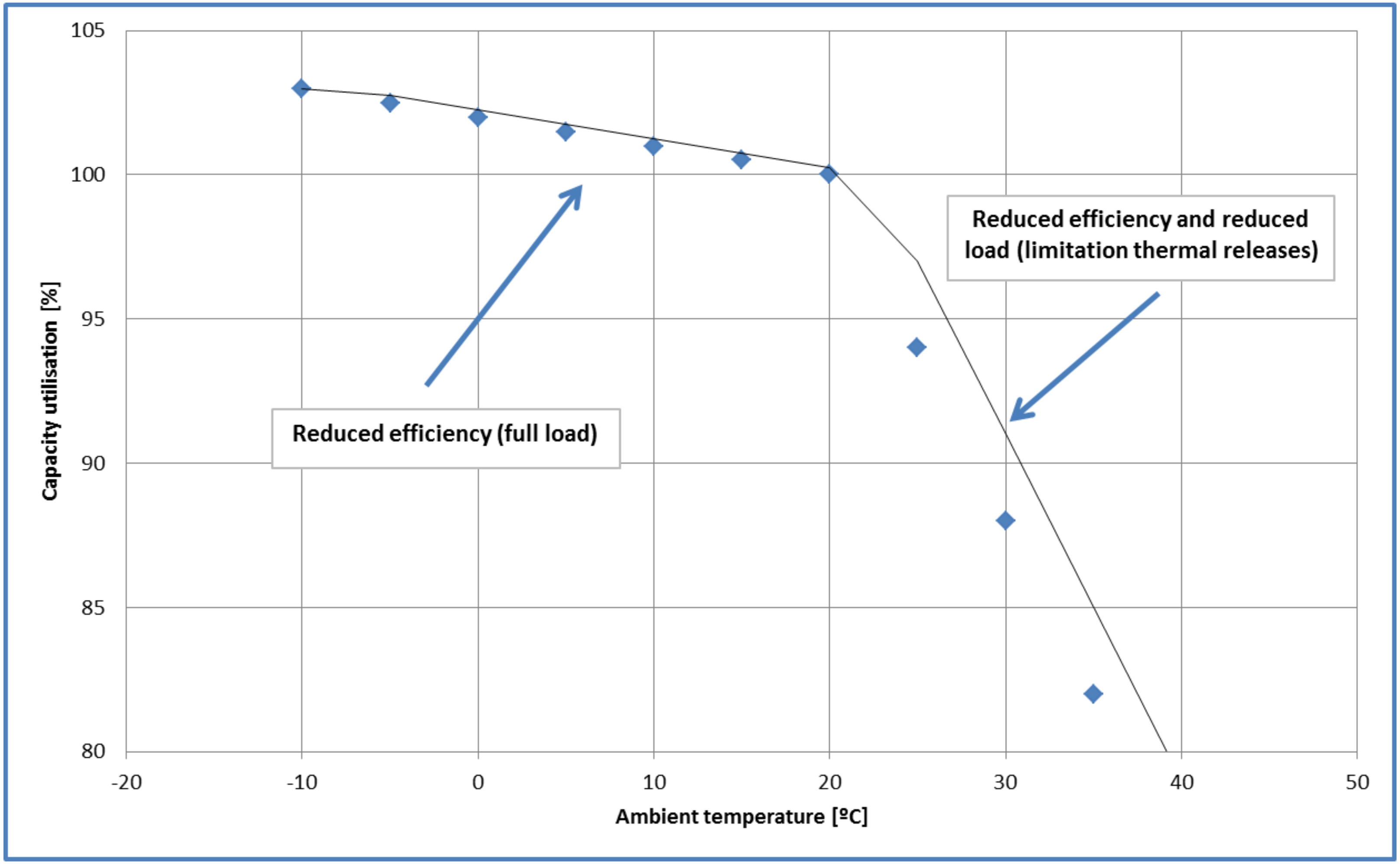


Essential Service Water System (ESWS) to remove residual (decay) heat: “Ultimate Heat Sink”

SAFETY

Cooling for thermo-electric power plants

Thermal Efficiency decreases with increasing cooling temperature
(thermodynamics AND environmental regulations)



What data do we have? (1)

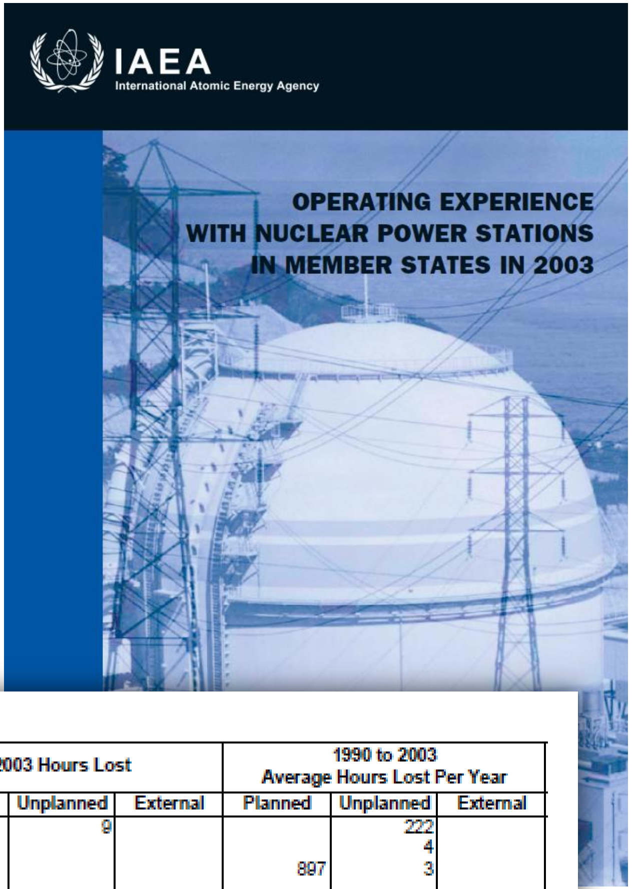
- IAEA Outage data (loss of kWh production) according to several classifications

2003 Operating Experience

FR-61 GOLFECH-1

6. 2003 Outages

Date	Hours	GW(e).h	Type	Code	Description
25 Jan	21.0	27.0	UF3	Z	VARIOUS, UNIT OPERATIONAL PROBLEMS (SOME NOT EXPLAINED)
04 Mar	1671.0	21.0	XP	K	OPERATION WITH POWER LIMITER BELOW MAXIMUM AVAILABLE POWER
11 May	8.0	2.0	PP	E	PERIODIC TESTING WITH LOAD REDUCTION OR SHUTDOWN
01 Jun	631.0	33.0	XP	K	OPERATION WITH POWER LIMITER BELOW MAXIMUM AVAILABLE POWER
02 Jun	31.0	19.0	XP	S	LOAD LIMITATION OR SHUTDOWN CAUSED BY INDUSTRIAL ACTION
13 Jun	16.0	7.0	UP3	A33	AIR COOLANT
22 Jun	9.0	12.0	UF3	A33	CIRCULATING PUMP
23 Jun	14.0	9.0	UP3	A16	STEAM GENERATOR INCLUDING SG BLOWDOWNS
01 Jul	697.0	27.0	XP	K	OPERATION WITH POWER LIMITER BELOW MAXIMUM AVAILABLE POWER
04 Jul	39.0	25.0	UP3	A32	FEEDWATER PUMP (EXCLUDING TURBINE-DRIVEN FEEDWATER PUMP)
01 Aug	335.0	20.0	XP	K	OPERATION WITH POWER LIMITER BELOW MAXIMUM AVAILABLE POWER
15 Aug	406.0	532.0	XF	N	COMPLIANCE WITH REGULATIONS CONCERNING RIVER TEMPERATURES
01 Sep	216.0	3.0	UP3	K	VARIOUS, UNIT OPERATIONAL PROBLEMS (SOME NOT EXPLAINED)
10 Sep	178.0	91.0	XP	K	LOAD VARIATION
16 Sep	81.0	4.0	XP	K	OPERATION WITH POWER LIMITER BELOW MAXIMUM AVAILABLE POWER
01 Oct	258.0	59.0	XP	K	FREQUENCY CONTROL, OPERA
02 Oct	167.0	5.0	XP	K	OPERATION WITH POWER LIMIT
01 Nov	476.0	20.0	XP	K	FREQUENCY CONTROL, OPERA
02 Nov	25.0	3.0	XP	K	REMOTE LOAD DISPATCH CONT
03 Nov	176.0	2.0	XP	K	OPERATION WITH POWER LIMIT
04 Dec	672.0	49.0	XP	S	LOAD LIMITATION DURING STR



7. Full Outages, Analysis by Cause

Outage Cause	2003 Hours Lost			1990 to 2003 Average Hours Lost Per Year		
	Planned	Unplanned	External	Planned	Unplanned	External
A. Plant equipment failure		9			222	
B. Refuelling without a maintenance					4	
C. Inspection, maintenance or repair combined with refuelling				897	3	
D. Inspection, maintenance or repair without refuelling				81		
E. Testing of plant systems or components				85		
H. Nuclear regulatory requirements					3	
K. Load-following (frequency control, reserve shutdown due to reduced energy demand)					13	
N. Environmental conditions (flood, storm, lightning, lack of cooling water due to dry weather, cooling water temperature limits etc.)			406			
Z. Others		21				
Subtotal	0	30	406	1063	245	0
Total	436			1308		

What data do we have? (2)

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Outages per cause from 2004 to 2011			
Cause	**Duration (1000 h)**	**Energy Loss (TWh)**	**No. of events**
A	2 728	648	12 039
B	299	149	236
C	3 391	2 807	2 216
D	600	307	1 336
E	140	28	6 238
F	213	134	54
G	496	376	80
H	284	65	483
J	642	58	1 327
K	2 007	165	4 873
L	47	14	608
M	38	37	35
N	2 776	112	3 215
P	6	5	23
R	438	47	642
S	874	78	836
T	125	1	88
U	0.07	0.03	1
Z	561	26	746
Total	15 665	5 054	35 076

IAEA PRIS database

Outages caused by environmental conditions

0	Warm cooling water
1	Cold cooling water
2	Flood
3	Low water level
4	Lightning / thunderstorm
5	Storms (typhoon, hurricane)
6	Other weather-related
7	Non-W env.: pollution
8	Unspec. env. restriction
9	Earthquake / tsunami
10	Seasonal variation CWT
11	Excluded: not environmental (market, techincal, cleaning)

17.7% duration
2.2% Energy Loss
9.2% Events

What data do we have? (3)

NEA Nuclear Energy Agency

OECD

- IAEA/NEA incident database, data from national reports, nuclear regulators and operators. Examples of shut downs due to external events:
  - Loss of "ultimate heat sink", Cruas NPP, France, December 2009 (due to blockage of ESWS intake by massive quantity of algae)
  - CWS water intake blockage, Olkiluoto NPP, Finland, January 2008 (due to frazil ice)
  - CWS water intake blockage, Osarshamn NPP, Sweden, September 2013 (due to jelly fish)
  - Loss of off-site power, Dungeness B NPP, UK, October 2013 (caused by debris landing on power lines during storm)
- Other data provided in the course of the NEA study in the form of "**case studies**"
- Data about incidents themselves, but often information about measures required by the regulators to reduce the risks of similar events.

Olkiluoto NPP

Reactor trip at Olkiluoto 2 as a result of the freezing of coolant

Seawater cooled rapidly in front of the Olkiluoto nuclear power plant on the morning of Saturday 5 January 2008. The frazil ice formed as a result of this cooling blocked the circulating water screening filters of Olkiluoto 2 and weakened the flow of the seawater used as coolant in the plant. As a result, a turbine trip occurred at the plant unit, leading to a reactor trip. In connection with the event, a steam

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Jellyfish cause stop of production at unit Oskarshamn 3

Published 2013-09-30 13:27

At noon on Sunday 29 September, the production at unit Oskarshamn 3 (O3) was manually shut down due to a large amount of jellyfish present at the cooling water intake.

The operations management at unit O3 chose to disconnect the facility from the grid at noon on Sunday due to a large amount of jellyfish present at the cooling water intake. This decision is a preventive safety measure in order for the unit to not be automatically shut down due to too low cooling in the condenser.

The function of the cooling water in the condenser is to cool down the steam so that it is reformed in to water again, and subsequently brought in to the reactor vessel. This cooling water has no connection to the cooling of the reactor vessel.

What data do we have? (4)

Adaptation Measures in Finnish NPPs

(TVO/Pekka Viitanen, Fortum/Reko Rantamäki, FMI/ Pekka Alenius, Hilppa Gregow, Milla Johansson, Pauli Jokinen, Kirsti Jylhä, Hanna Mäkelä, Seppo Saku, Aalto U./S. Syri)

- **Olkiluoto NPP:**
  - Measures to prevent blockage (by snow) of air intakes of heating, ventilation and emergency diesel generators
  - OL3: heating of air intakes
  - Pumping “warm water” upstream of cooling water intake to prevent frazil ice formation

- **Loviisa NPP:**
  - Construction of air cooling system (tower) to supplement sea cooling in case of frazil ice or other pbs with sea water
  - Heating water intake grids to prevent frazil or pumping warm water upstream
  - Study on building deep water intake in case of high sea temperatures (possibly economical in the future)

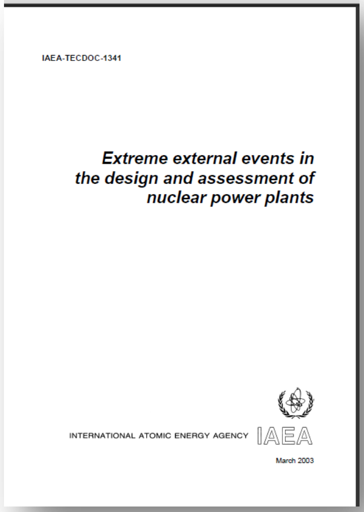
Finnish Case Study (NEA study)

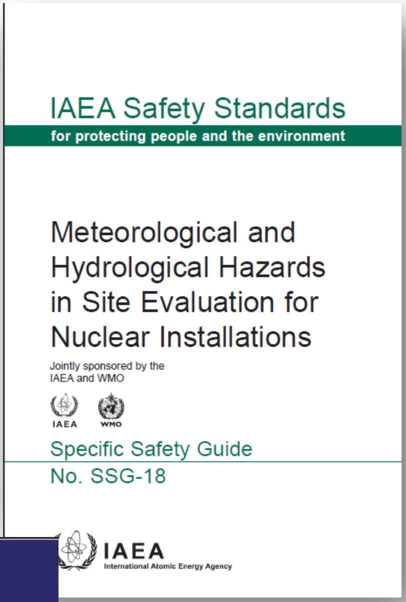
Estimating the cost of 'inaction'

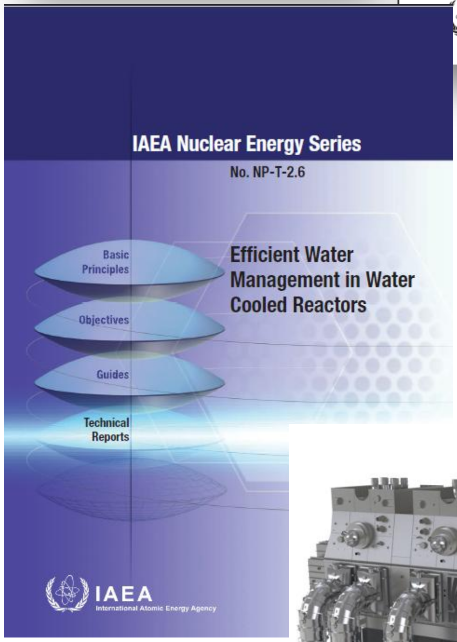
- Direct impact:
  - Loss of production due to partial/full outage because of:
    - compliance to environmental regulations (e.g. thermal releases) or safety regulations (max. temp. cooling water for safety-related cooling systems) or
    - Event affecting the operation of the NPP (for instance the cooling system) or
    - Event affecting the transmission grid.
  - Loss of efficiency due to higher cooling water temperature (data not publically available)
  - Cost of repairs, refurbishment, safety upgrades
- Indirect impact:
  - Purchase by utility of power on "spot market" to compensate for loss of production
  - Compensation of customers (energy-intensive industry) required to reduce their electricity consumption (load management/shedding)
- Cost assessment methodology needed (also for comparison across energy sector) – **and to make a better case for adaptation!**

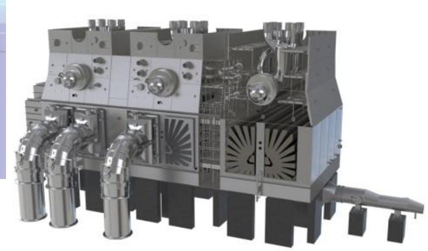
Dealing with CC in the nuclear sector

- Guidelines (e.g. siting), safety standards, safety assessments and regulations
- Design (e.g. taking into account CC risks)
- Technology (e.g. cooling technologies)
- Planning and plant management (e.g. based on demand forecast, outage planning)
- Demand-side management





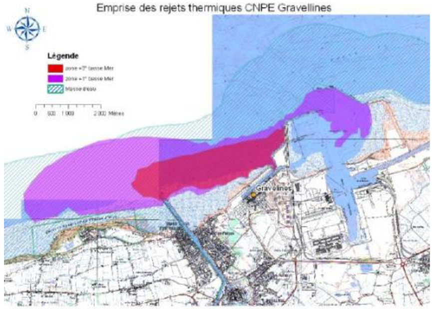




Associated R&D needs (1)

- <u>Cooling:</u> (objectives: reduced usage of water / reduced impact)
  - Cooling technologies:
    - Closed cooling systems, hybrid systems
    - “low” profile cooling towers (public acceptance)
    - Dry cooling
    - More efficient Heat Exchanger equipment (e.g. Condensers)
  - non-traditional water resources (e.g. Treated waste water)
  - Innovative reactor designs (e.g. Gen IV, higher operating temperatures/efficiency) - Advanced power conversion technologies (e.g. SCO2)
  - Modelling of cooling water intakes & thermal releases to reduce environmental impact

Palo Verde NPP, largest NPP in the United States, uses treated waste water from city of Phoenix and other municipalities.



Associated R&D needs (2)

- <u>Weather forecast:</u> (objectives: improved management of supply [e.g. Outages] and demand)

  - Planning based on better assessment of demand.
    - "air temperature" is most important parameter driving electricity demand.
    - predicting consumption with 1 to 2 weeks lead-time can help optimise selection of generating units to meet demand.

  - Planning outages:
    - planning refuelling and maintenance outages during peak heat periods (provided outages can be balanced by increased production at other sites or imports) for most vulnerable units (located on rivers)
    - After 2003 heat wave, EDF reviewed its maintenance planning to ensure operation of all coastal units during summer

  - Improving forecasting tools:
    - to select, size and engineer future plants, test robustness against CC / extreme weather events.
    - Multi-scale approaches to combine long-term forecasts (several decades, time scale of investment / construction / operation) with short term projections (for operational purposes, fleet management)

Associated R&D needs (3)

- <u>Safety assessment:</u> (safety case for NPPs operating for several decades, taking into account the possibility of extreme weather events; to help design "barriers")

  - Two types of safety assessment:

    - Deterministic (conservative) / based on a realistic "worst case scenario"

    - Probabilistic safety assessment (PSA)

    - But PSA methodology requires "historic data": e.g. "10000 year flood".

      - Usually recorded data exists for ~ 100 years.
      - Extrapolation.
      - But what about CC-events for which no data (frequency, amplitude) exists, only "projections" (e.g. IPCC) ?

Some preliminary conclusions

- **New plants:** (typically 60 year lifetime → operation until ~2080)
  - Design, siting – take into account CC risks.

- **Existing plants:**
  - Siting and safety case take into account (known) extreme weather events
  - Safety requirements are a driver for change (often, safety upgrades improve CC resilience too)
  - For non-safety issues: (e.g. thermal efficiency, outages due to environmental reasons), "economical decision"

INACTION

- *cost of adaptation vs. electricity market 'economics' (wholesale price, overcapacity)*
- *adaptation can lead to reduced power output (e.g. closed cycle vs. direct cooling)*
- *single plant operator*
- *remaining lifetime (~10y)*
- *"low" number of events*

ADAPTATION

- *safety requirements*
- *security of energy supply*
- *fleet operator*
- *remaining lifetime (~20-30y)*
- *"high" number of events*

Need to make the economic case for resilience

Some preliminary conclusions

- Importance of addressing (generation + grid + consumers) together to design resilient energy systems

- (Short term) economics not enough to drive changes:

  - Role of governments to put in place investment framework for long term
  - Role of regulations to drive technological changes.

- In terms of R&D needs / activities with respect to nuclear power & CC:

  - Cooling technologies *to reduce water dependence*
  - Forecasting methods *to improve plant/fleet management*
  - Safety assessment methods *to address future CC events*
  - Economic assessment methodology *to make a better case for adaptation.*

→ ***NEA study & recommendations to be published 2nd half 2014.***