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Daya Bay 20 Years and Beyond:

Challenges and Opportunities for the Nuclear Industry
An International Viewpoint

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Challenges for China's Nuclear Programme

An UK viewpoint

1. **Drivers and plans for nuclear investment** in both UK and China;

2. Nuclear safety – what are real issues?

3. People as the important enabler/constraint;

4. Capital costs provide a challenge.

Why Nuclear in 21st Century? – Climate Change

- **Global targets** set for total carbon dioxide (and other GHG) emissions;

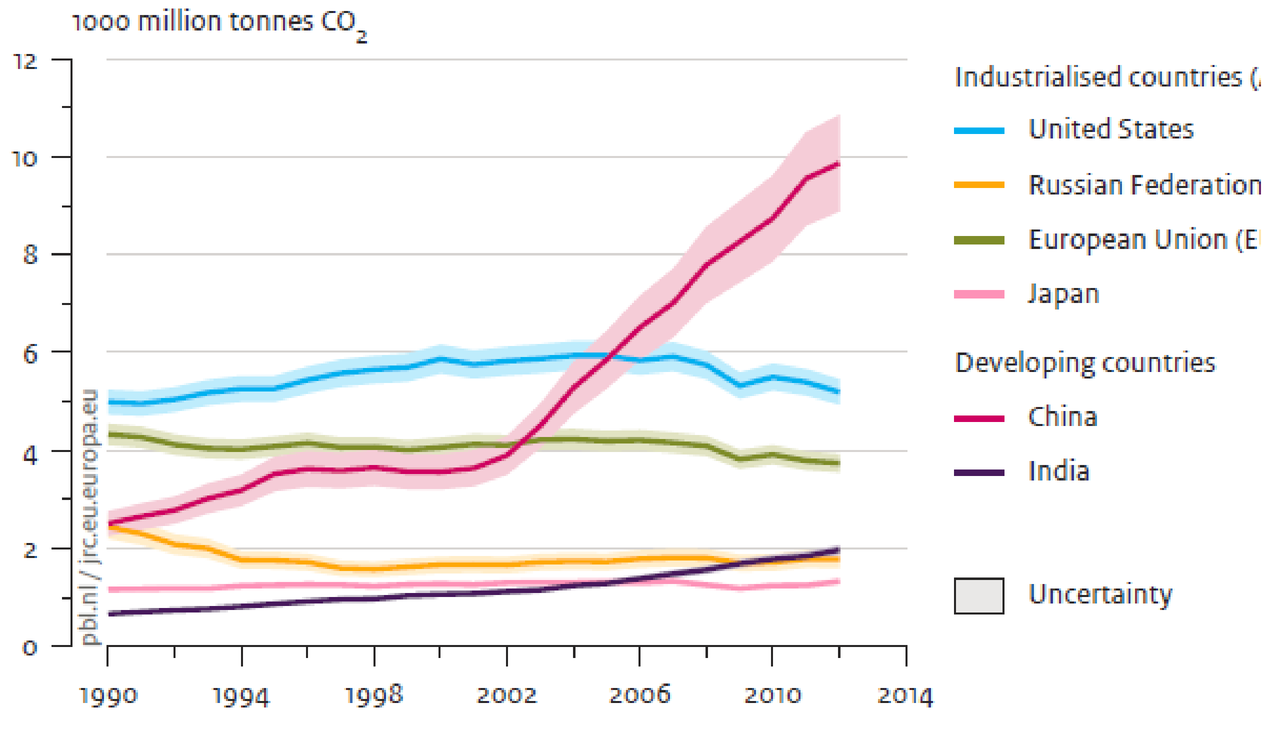
  2 deg C consistent with IPCC global 3,200 bn tne of CO_2

  Emitted to date 2,000 bn tne

  Current rate 40 bn tne pa growing at 2.2%

- **Specific targets for 2050**:

  - Developed countries - 80% cuts from 1990 levels, and
  - Global average < 2 tne CO_2 per head, world wide.



: EDGAR 4.2FT2010 (JRC/PBL, 2012); BP, 2013; NBS China, 2013; USGS, 2013; WSA, 2013; NOAA, 2012

UK Energy – a mix of clean energy sources

UK Government **energy policy is now:**

- **Double the scale of electricity** in our energy mix by 2050: - supplied by:
    - 30,000 large **wind**mills ~80GWe (nominal) or 20-25 GWe (mean)
    - Some **gas** to fill the gap, balance the system and set the price level;

- Committed plan for 16 GWe by ~2035, plus for 2050 either:
- Scenario **0** – no more nuclear - CCS?
- Scenario **1** – 50% of supply 40 GWe
- Scenario **2** – Max possible? 75 GWe

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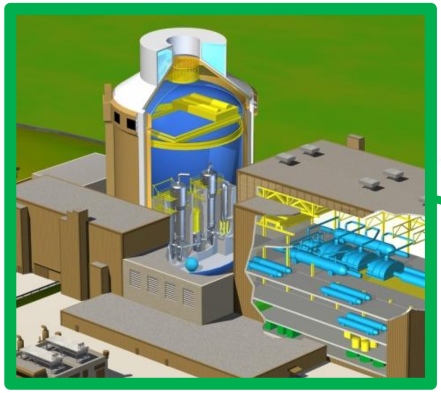
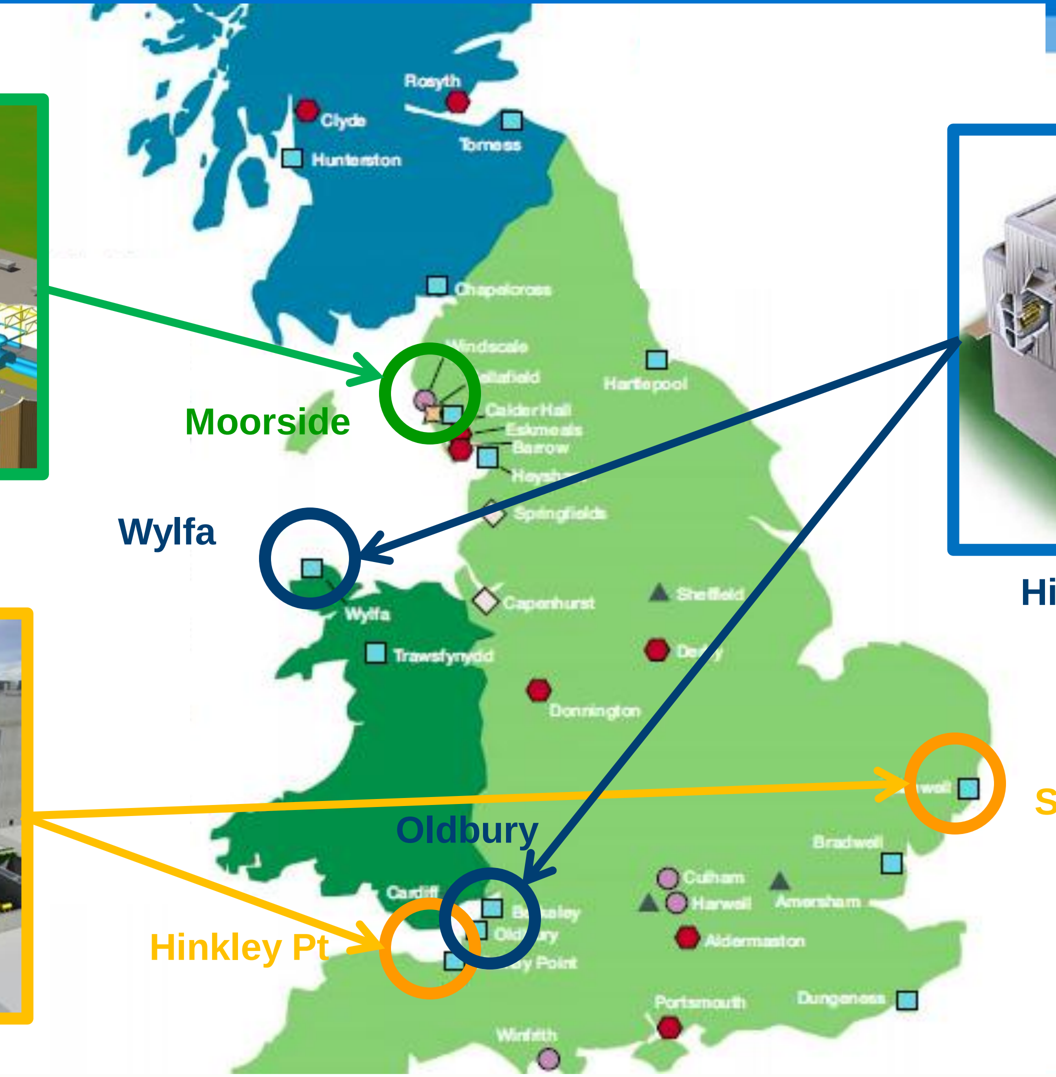
Nuclear New Build Sites – 16 GWe



Westinghouse AP1000

AREVA - EPR



Hitachi - ABWR

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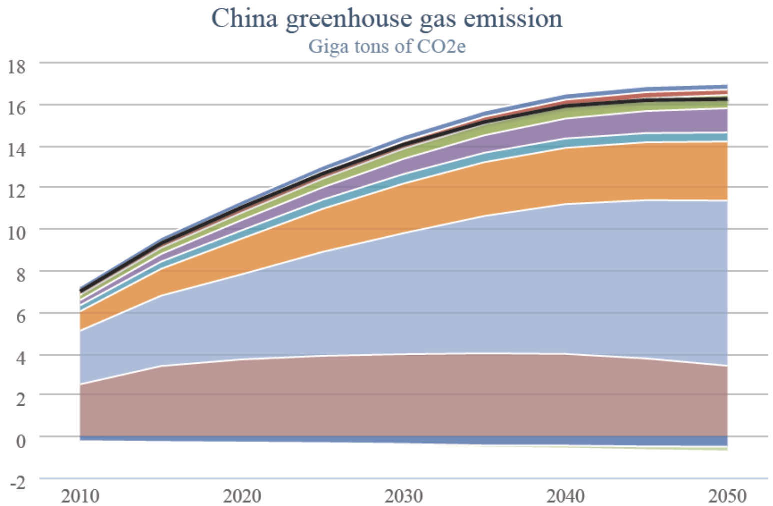
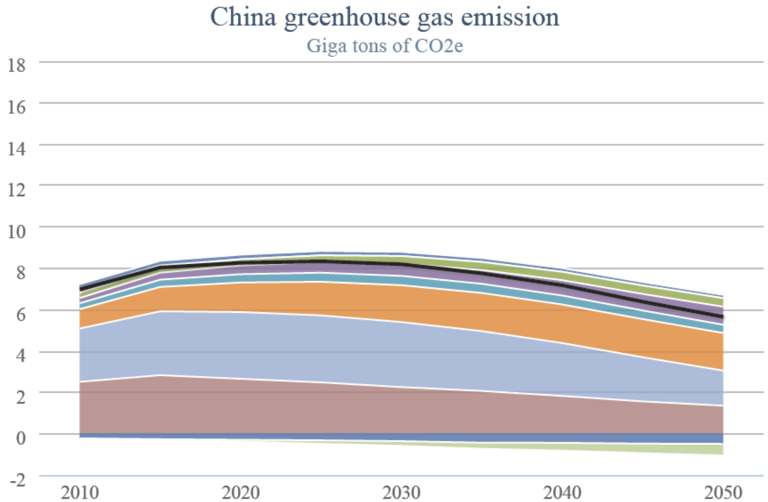
Challenge of Climate Change - China

- Without wholesale change increase emissions of CO_2 per head from **~6 tne** today to **>12** tne in 2050 – versus target global average **2 tne** per head by 2050;
- Any successful strategy will include: Radical energy saving; Step change in efficiency – industry and materials, electricity, transport - then Electrification of heating and transport;
- Even with extremely ambitious renewables (1,000 GWe) and very large amounts of nuclear (350 GWe) emissions curtailed only to **~5 tne** per head in 2050;



China 2050 Pathway 'Pessimistic' scenario



Dr Yang Yufeng scenario with added nuclear

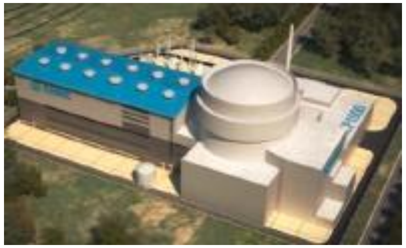
Phases/Technology

1 - Experimentation: own designs CPR300/600, French M3 plus CANDU 6

CPR 600

Qinshan Phase 3

2 - Exploring what to standardise: 3-loop ACP/ACR1000, EPR and AP1000

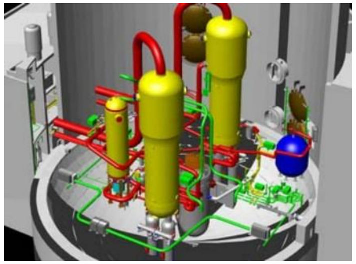


ACP1000

EPR Taishan

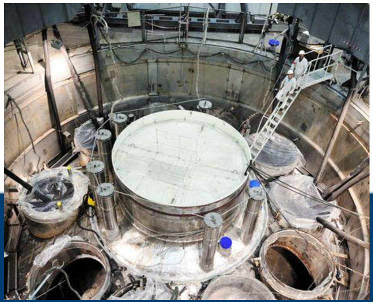
3 - Volume application of indigenous reactor Hualong 1 & AP1000/CAP1400

Hualong 1 Model



CAP1400 Circuit

4 – Advanced & fast reactor development, starting with BN800 – including HTGR & MSR etc?



BN800 in Russia

Challenges for China's Nuclear Programme

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Progress in Nuclear Safety

- After 14,000 reactor years of LWR nuclear experience:

- Does the Fukushima accident mean we have to raise safety standards in a wholesale manner?
  - **Safety Regulation** – needs to be effective;
  - **Major accidents** beyond the design basis – extending boundary in a rational way;
  - **Reactor systems** design – major improvements in design have been made.

Progress in Nuclear Safety

- **Hazard to the Public** = **Core Damage + Containment by-pass**;

Core damage frequency improvements:

~1 in 1,000 yrs

LWRs as built in 1970s

Designed for limited set of standard accident, plus containment for DBEs

<1 in 10,000 yrs

Post TMI build or as modified

Probabilistic Risk Analysis
LOCA protection & better control systems

<1 in 100,000 yrs

Modern Systems 1990s: ABWR, Sizewell B

Designed-in LOCA prevention & protection
Common cause addressed

~1 in 1,000,000 yrs

Gen III+: EPR, AP1000

Design for External & Internal hazards
Whole core accident prevention/mitigation
Improved Containments

- Design safety performance has been **improved by at least factor of 100** since 1980.

Progress in Nuclear Safety

- Modern reactors with their complex safety systems have design estimates of:
  - Core damage frequencies — between 10 and one in million years
  - Major release frequencies — between 10 and one in ten million years
- Such frequencies are in line with civil aircraft reliability/hazard levels
  – which are both 'state of the art' - are accepted as reasonable risks.
- Currently < 500 power reactors world-wide, expansion may get to 2,000 by 2050;
- Likelihoods due to design feature of:

	Now	2050
Core damage likelihood	1 in 200/2,000	1 in 50/500 pa
Major release likelihood	1 in 2,000/20,000	1 in 500/5,000 pa

- **Actual plant safety** will now be dominated (like in aerospace) by **human factors** failings in construction, quality and in operation – this is the **focus for improvement.**

Progress in Nuclear Safety

Human factors in:	**Depends on:**	**Guaranteed by:**
• **Design**	Engineering competence	Independent Design Assessment
• **Construction**	Quality & skills	Independent inspection
• **Operation**	Experienced staff	Effective oversight
• **Maintenance**	Planning & understanding	Competence staff & inspection

Nuclear safety culture of high standards, rigour & openess to learning

Challenges for China’s Nuclear Programme

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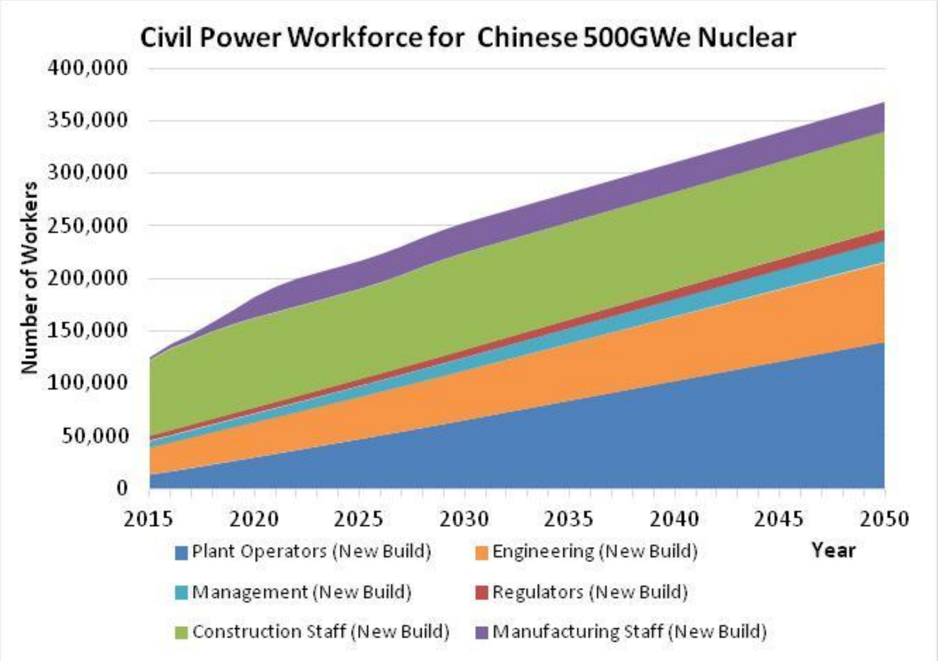
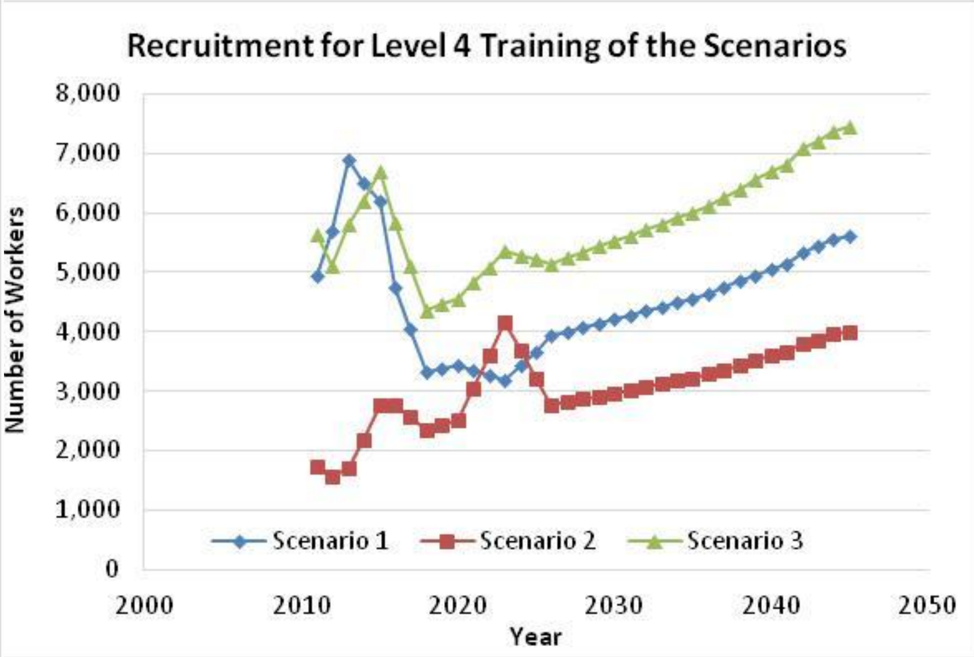
Skilled and Experienced Manpower

- China civil nuclear manpower modelled for three scenarios for 2050 – capacity:
  1. 250 GWe
  2. 400 GWe
  3. 500 GWe

  - not including advanced systems.

- More ambitious plans may required ~350,000;
- Key skills in design, construction & operating nuclear Masters/PhD) scientist & engineers;
- Experience & safety culture years to acquire;
- Level 4 engineers required up to 4-7,000 pa – versus current capacity ~2,000 pa.





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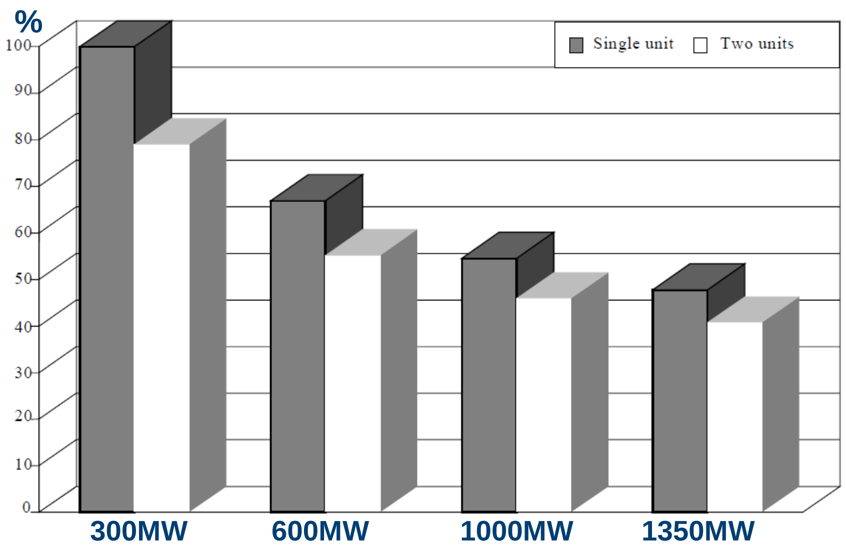
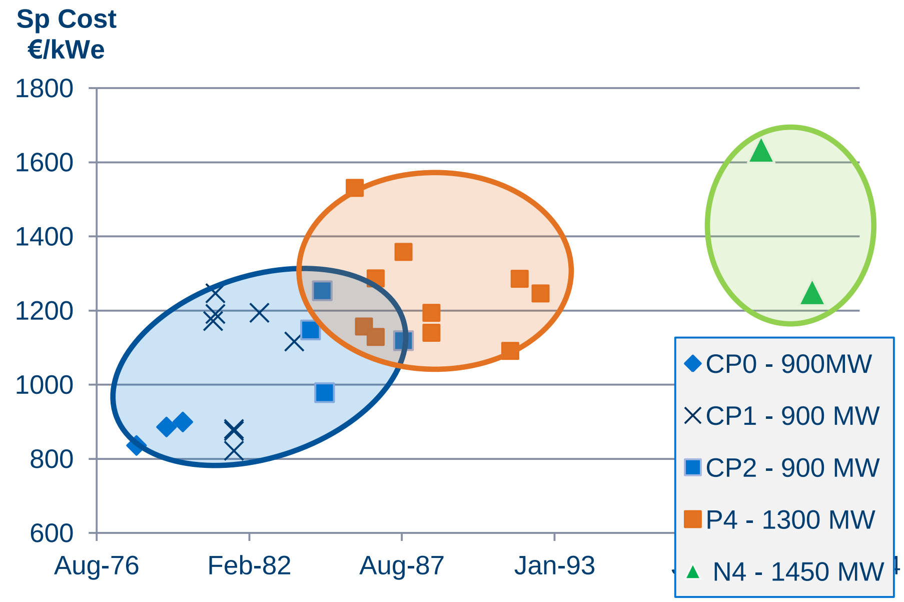
Scaling: Forecasts meet Reality - France

- Forecasts based on power scaling effect (OECD: scaling index -0.5 to -0.2) are not supported by the data for capital costs of France – 58 reactors.



Forecast Scaling Effect - France

OECD-NEA Reduction of Capital Costs in NPP 2000



French Data - Specific Construction Costs €/kWe 2010

Cour de Compte (2012)

What lessons might we learn?

- Safety in 21st century will be determine more by **human performance** (& tough regulation) than by more complex designs;
- **Skilled and experience manpower** will be at premium for the massive nuclear programmes being planned;
- **Nuclear skills and safety culture** are key to:
  - Safe operation,
  - Gaining and retaining the trust of the public in nuclear energy
- **Cost of nuclear energy** is dominated by initial construction cost;
- Nuclear, **bigger** is not always better, nor **necessarily cheape**r;
  - Standardisation of design and national construction productivity/quality programmes are the keys to the cost effectiveness of nuclear energy.

Questions?