EDF Energy – Nuclear Generation
The AGR Design, Fukushima and More

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Purpose of this Document

- To provide a brief on;
  - The AGR Design
  - The response of the AGR to loss of all key supplies

- To prompt some discussion on aspects to consider when designing reactors

The Trend of Commercial Reactor Design

Background

- The capital cost of nuclear power stations is high
  - This is offset by low fuel costs
- As a result, the reactors have tended to get bigger driven by economies of scale
  - Reactors can be 4500MWth and 1650MWe
- The current generation of reactor designs do have many trains of back up equipment to ensure adequate reactor cooling either in normal or fault condition;
  - The many trains of back up equipment does add to the complexity of the power station
  - The safety assessment does therefore need to be comprehensive
- The size and complexity of the reactors does mean they take a long time to build although measures are taken to build them as fast as possible;
  - The length of time to build adds to the commercial risks hence costs of the project

Is big beautiful?
Is the complexity of back up plant impressive?

The AGR Design

The AGR Design: 1500MWth/660MWe

- The AGR was a natural evolution from the MAGNOX and is unique to the UK

- The drive for greater thermal efficiency required a higher temperature reactor
  - With a requirement to produce steam at a pressure (165Bar) and temperature (540 Deg C) compatible with "normal" 660MWe steam turbines

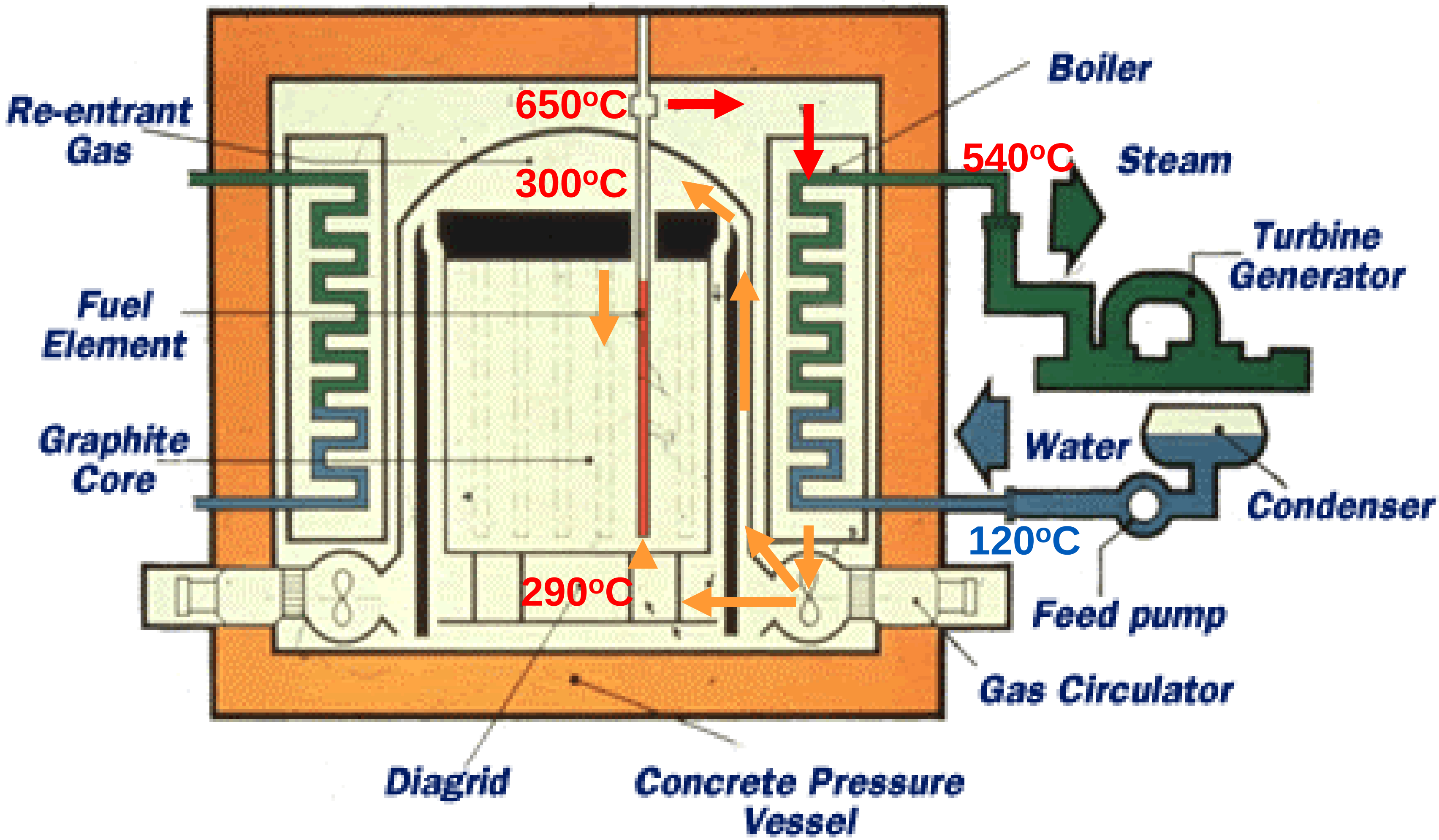
- The reactor gas temperatures can reach 650 Deg C and fuel cans c800 Deg C in normal operation;
  - The fuel cans therefore needed to be stainless steel
  - And this in turn required the use of enriched Uranium fuel
  - The fuel temperatures also required the use of Uranium Oxide fuel

- The first large electricity producing AGRs started operation in 1976 (Hinkley/Hunterston) and the last was commissioned in 1988 (Heysham 2/Torness)
  - There are seven AGR Stations with 14 reactors

- The early AGRs have had significant safety upgrades to meet modern standards
  - But even the Sizewell B basic (USA) design had to be upgraded to meet modern UK standards

The AGR is a higher temperature reactor than the PWR with higher thermal efficiency

The AGR Plant



The AGR Steam Generators and "Reactor Coolant Pumps" are inside the Reactor Pressure Vessel

The Inside of an AGR…

The “Hot Box”

Below the “Hot Box”

Top of the Core

The AGR Refuelling

- The AGR was originally designed for on load refuelling which is carried out at 4 of the 7 AGR Power Stations;
  - The other 3 Power Stations carry out refuelling when shutdown
- The on load refuelling power stations could operate for up to 3 years before shutting down for the “Statutory Outages”;
  - A big advantage over a light water reactor
- However, the AGR Refuelling plant is complex to operate and maintain;
  - In reality, they can limit the yearly output from the Power Station
  - A big disadvantage compared to a light water reactor

The AGR Refuelling plant is very complex
When designing a reactor, think of the refuelling mode and plant design

AGR and PWR: Faults Which Are Considered In The Design

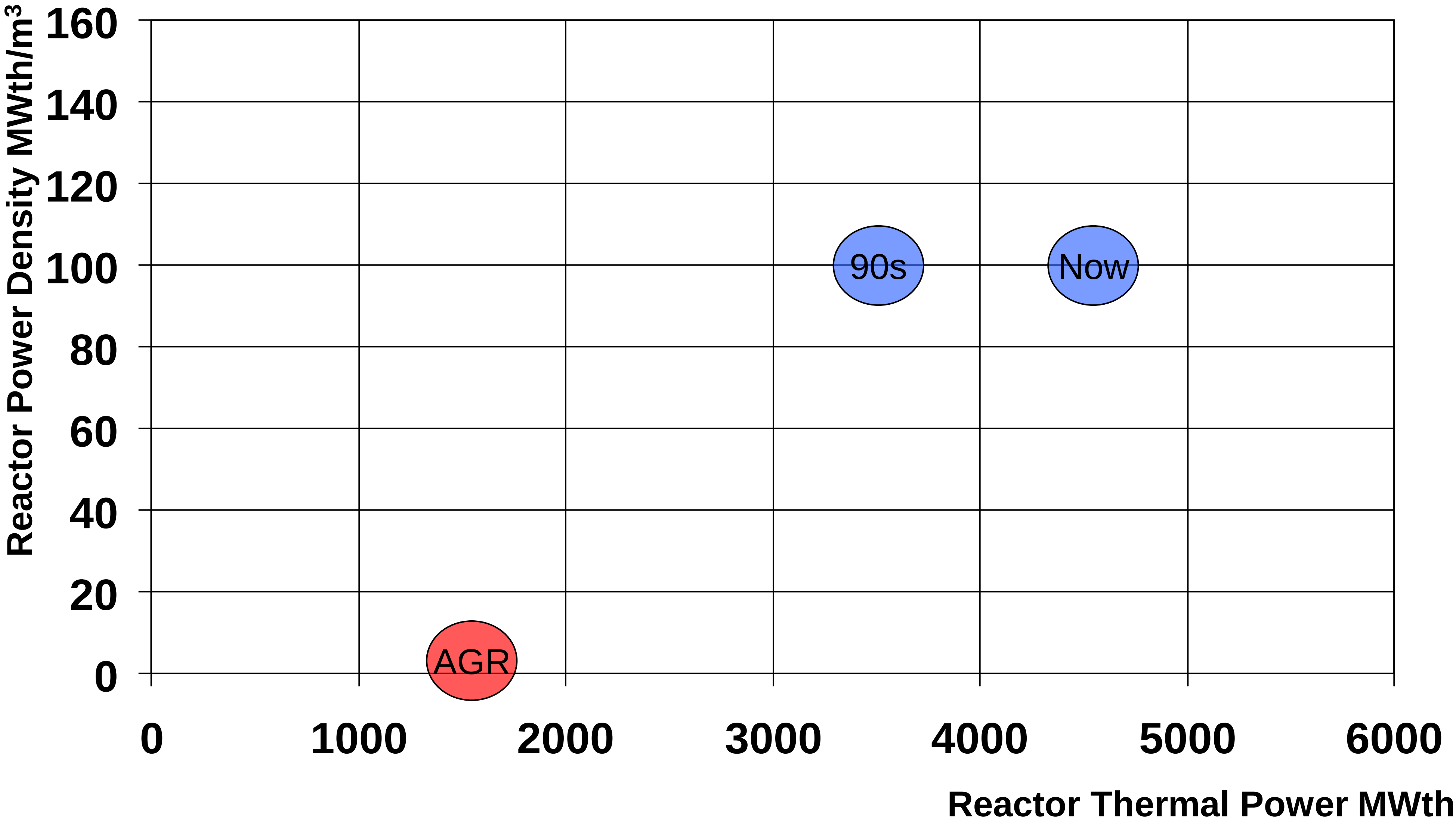
The following is a summary of the differences between the AGR and the Typical PWR fault schedules or the assessment of the faults

- **Plant faults**
  - The main difference is that the AGR boiler pressure is much higher than the reactor (160 vs 40 Bar) so that steam generator tube failure results in boiler water ingress ***into*** the AGR primary coolant
- **Internal Hazards**
  - The main difference is that the AGR has much hotter steam and primary circuit gas than a PWR hence the plant qualification must tolerate these higher temperatures
- **External Hazards**
  - No significant differences: Both include seismic, extreme flooding, wind, temperature
  - The magnitude of external hazards is assessed for a 1 in 10,000 year return frequency event

The AGR does have some more onerous plant & internal hazard faults because of its higher temperature and pressure but the AGR and PWR external (natural) hazards are the same

Response in Extreme Fault Conditions

Reactor Power and Power Densities



The AGR: Behaviour in Extreme Fault Scenarios

No cliff edge even in extreme scenarios…

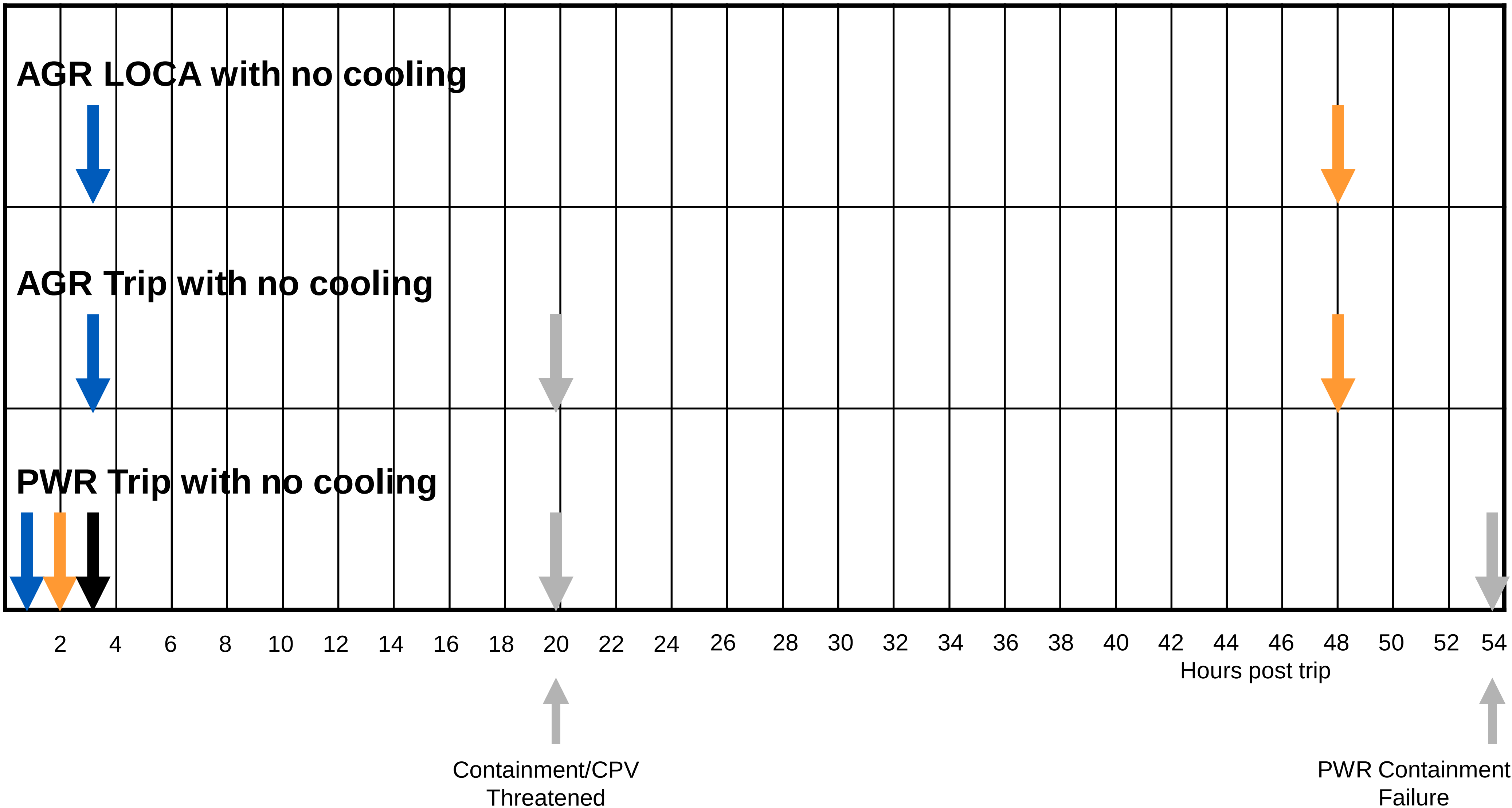
- The AGR's much lower power density and more built in thermal inertia allows for very benign post trip thermal hydraulic ("temperature") behaviour

- If an AGR tripped and shutdown with the reactor pressurised, it could tolerate no gas circulators and no boiler feed for many hours
  - The thermal inertia of the water remaining in the boilers and the graphite core providing an effective heat sink for the circulating gas
  - The natural circulation of the CO_2 transports the heat from the fuel to the remaining water and the graphite

- This is very useful for scenarios involving loss of grid (off site electrical supplies).
  - Significant rework of basic Sizewell B (USA) design was required to adequately address this area for the UK PWR

The AGR may be a higher temperature reactor but its thermal response to faults is much slower

Beyond Design Basis Events – Beyond Station Blackout



Why No LWR Type Containment for the AGR?

The AGR Design: LOCA and the Containment Issue

- The main AGR fault is associated with reactor depressurisation (its Loss Of Coolant Accident – LOCA);
  - The most onerous fault is assumed to be a failure of a reactor penetration at a frequency of 10^{-4} per year

The off site release is limited due to a combination of;

- The low reactor power density (40 times less than a PWR);
  - Coupled with a large thermal mass in the graphite moderator

- The primary coolant does not change phase in the fault (ie it remains a gas)
  - But CO_2 is pumped in to preserve a CO_2 atmosphere

- These two factors results in limited fuel can failures;
  - Best estimate number of fuel pin failures is 50 ie <0.05%,
  - Bounding assessments would move this number to about 1000 ie about 1% of pins

So the UK Safety Targets can be met for the AGR <u>without</u> one

However, it is essential that a PWR (or BWR) has a containment

In a severe design basis fault the AGR will fail between 0.05 and 1% of its fuel pins so the reactor does not need a LWR Type containment

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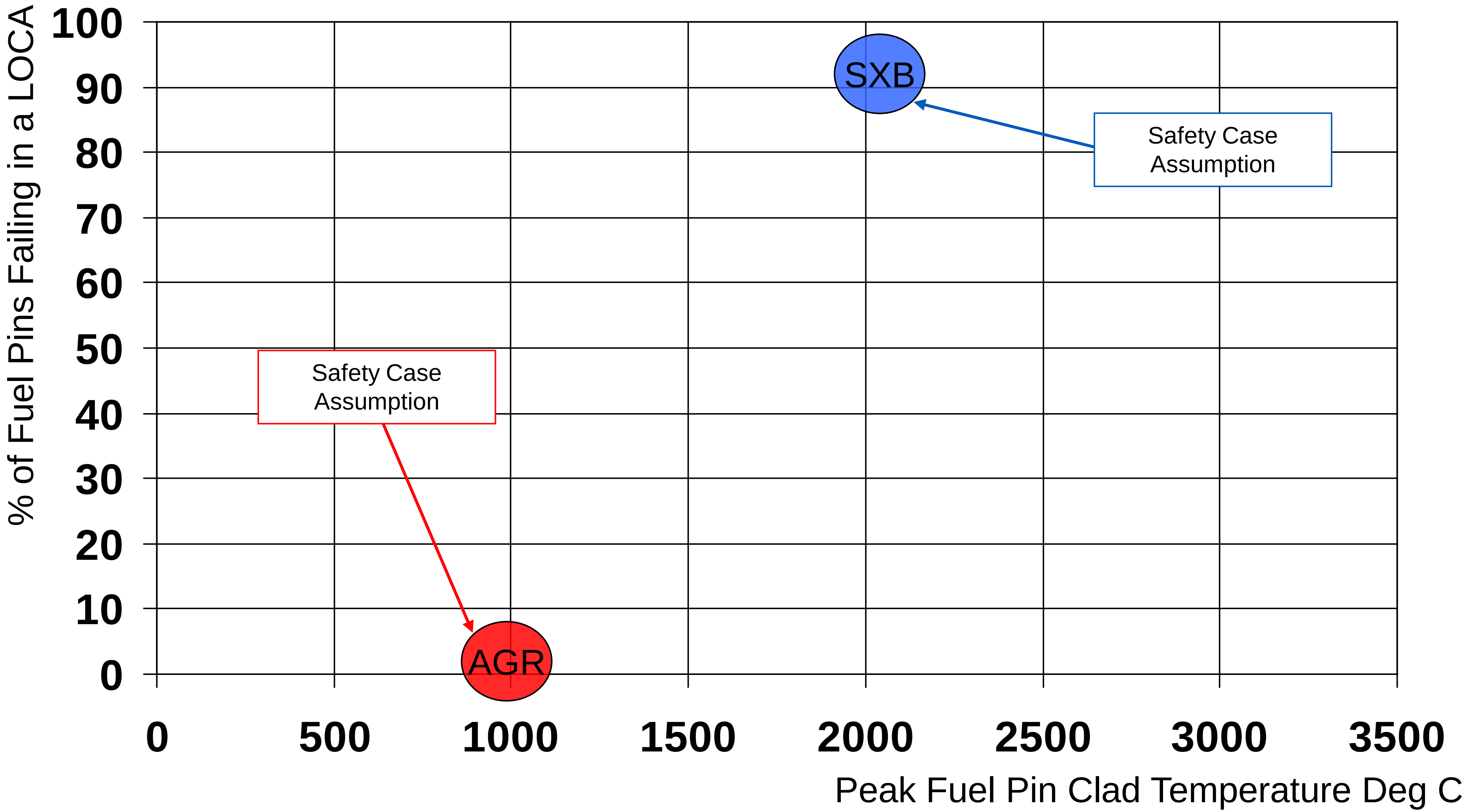
Fuel Pins Response to a Design Basis LOCA



Summary of the AGR

Summary of the AGR

- It is a high temperature reactor
- It is a low power density reactor
- It is a high thermal inertia reactor
- As a result, it is much slower to respond to post trip fault situations
- It doesn't need a LWR type containment to meet safety targets;
  - A water reactor does
- But it is complex to build;
  - Virtually hand built on site
- And its refuelling plant is complex
- The UK is on its own in solving the technical issues which can arise

The AGR Design has pros and cons
But its "pros" have helped it a lot in the severe faults stress tests

The AGR and Fukushima

- The slow thermal response of the AGR means it can tolerate loss of cooling for a long time

- This allows a different type of response

- The following are being carried out as part of the response to Fukushima;
  - Further thermal analysis to provide better advice to the operators
  - Increasing the resilience to external hazards for some plant systems

But the main area is;

- The provision of a greater range of back up equipment which can be deployed after a Beyond Design Basis event with protracted loss of power

And with it;

- Revised emergency arrangements to support the deployment of the extra back up equipment in a timely way

The slow response to loss of all cooling allows time to connect portable back up equipment

Some points to reflect on ..

Some Points to Reflect On ...(1)

- Ultimately reactor safety is the number one priority
- What do the Design Staff want?
  - What does “passively safe” really mean?
  - Is bigger better?
  - Are lots of back up systems better?
  - Are lower temperature reactors better?
  - Is a containment good?
- What do the Operations Staff want?
- What do the Maintenance Staff want?
- What do the Engineering Support Staff want?
- What does the business want?
- What do the public want

Do the designers really understand what all the Stakeholders want?

Some Points to Reflect On ...(2)

- Today we are designing reactors which may still be operating in 70 years

- The AGR design was conceived in the late 1950s/early 1960s;
  - And will be operating for many more years before decommissioning
  - They will help to fill the energy gap faced by the UK

- It is important that managing an ageing design and technology is considered from the outset

- What will you be doing in 70 years;
  - And what will the operators
    at that time think of your designs!!!!

Today's designers need to think of the world in decades to come

So Why Build PWRs and BWRs? - An AGR Person's View!

- Known technology
- Relatively simple reactors
- Simple refuelling plant
- Plenty of experience to base a design on
- The experience results in good reliability
- The simplicity and reliability results in more certainty in costs and risks

PWRs and BWRs use known technology and therefore pose lower commercial risk to investors

The UK EPR – Hinkley Point C

- 3,260 MW. Enough for 5 million homes
- Rebuilding a nuclear construction capability
- Opportunities for local firms
- Opportunities for local people
- £100m a year to regional economy during peak construction
- £40m a year to regional economy during 60 years of operation

The EPR is an evolution from successful existing designs

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Dungeness

Hinkley-Point B

Hunterston

Hartlepool

Heysham 1

Heysham 2

Torness

Sizewell

End