# Nuclear Resilience Modelling Framework for Improved Safety - NuRes

## Indo-UK Civil Nuclear Collaboration - Phase 4


University of Nottingham

University of Liverpool/Strathclyde

Loughborough University

Bhabha Atomic Research Centre (BARC)

Indira Gandhi Centre for Atomic Research


EPSRC
Engineering and Physical Sciences Research Council

DAE

RESEARCH COUNCILS UK INDIA

# People involved

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# Background and aim

Due to new emerging threat types and more complex reactor designs traditional risk analysis methods are no longer adequate.

Use the **resilience** philosophy to achieve reactor system **designs**, **operating regimes** and **recovery strategies**.

A **safe** and **rapid response** for any type of threat occurring at **any point** of its lifetime.

# Resilience metrics

- The project aims to produce a **mathematical modelling framework** which uses the **resilience philosophy** to achieve **reactor system** designs, operating regimes and recovery strategies which result in a safe and rapid response for any type of threat occurring at **any point of its lifetime**.

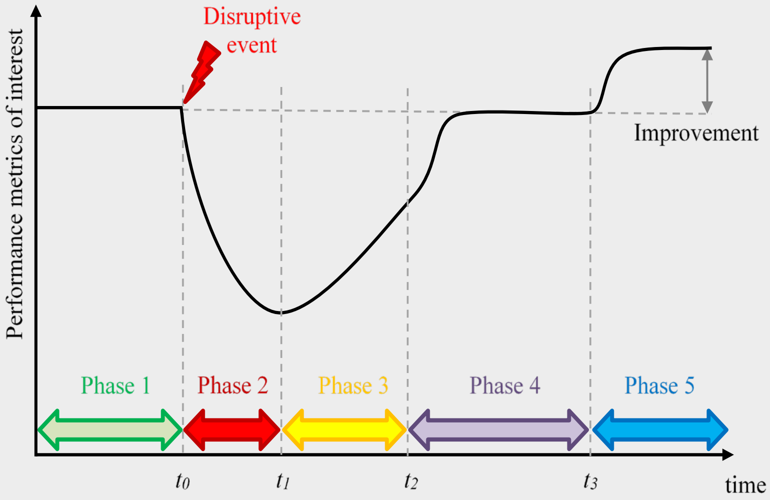
Safety rather than performance.

**Three** quantities are employed to characterise resilience metrics:

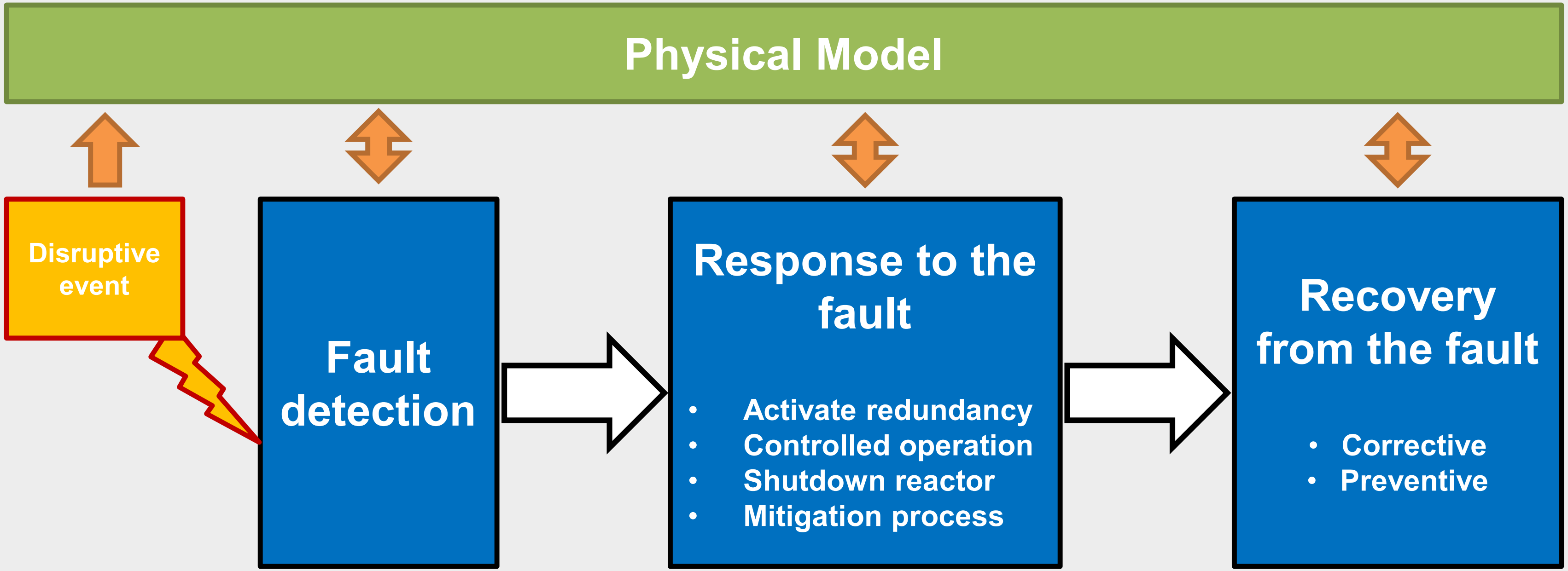
Absorptive capacity - Operation and health states of the reactor core.

Adaptive capacity - Maintain its performance.

Recoverability - Time needed to fully recover.



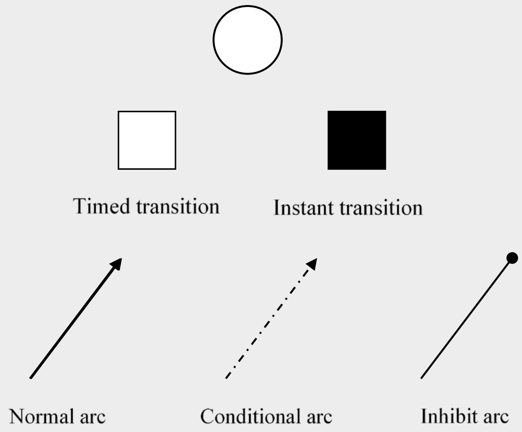
# Detection, Response and Recovery

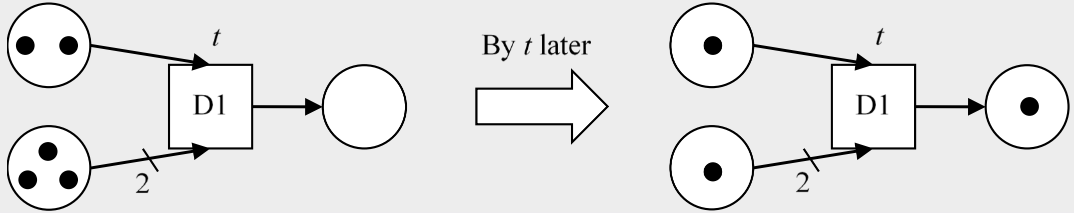


# Petri Nets

Petri Net (PN) consists of **three** basic elements:

- **Places** (circles) - represent possible states of the system
- **Transitions** (rectangles) - are events or actions which cause the change of state
  - Immediate (filled)
  - Timed
- **Arcs** (arrows) - simply connects a place with a transition or a transition with a place



# Petri Net Modelling Structure

- Reactor System Petri Net (RSPN)
- Immediate Response Petri Net (IRPN)
- Mitigation Process Petri Net (MPPN)
- Recovery and Maintenance Petri Net (RMPN)

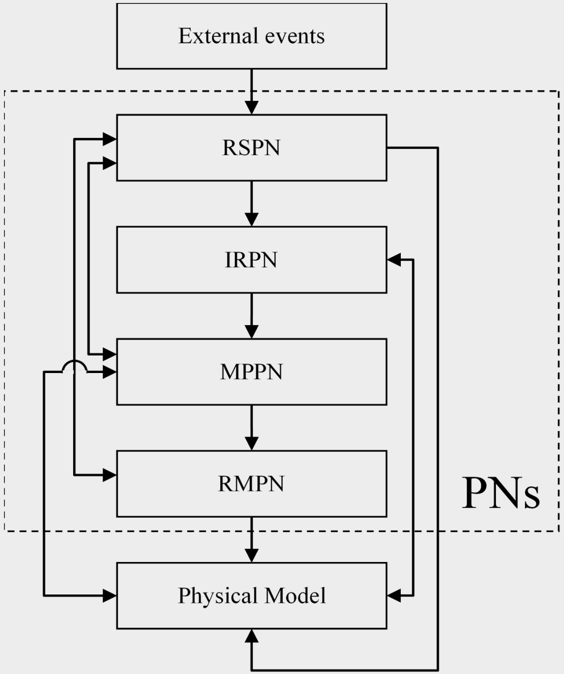



Figure: Overall structure of PN model

# Station Blackout (SBO)

Activate On-site Power

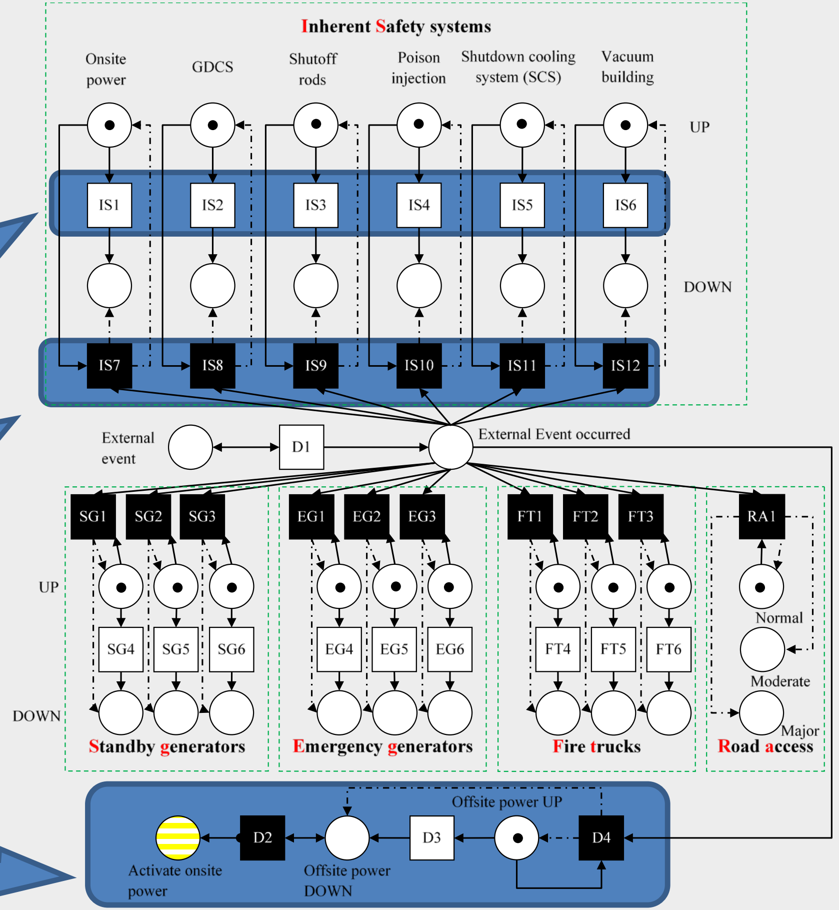





Figure : Reactor System Petri Net (RSPN)

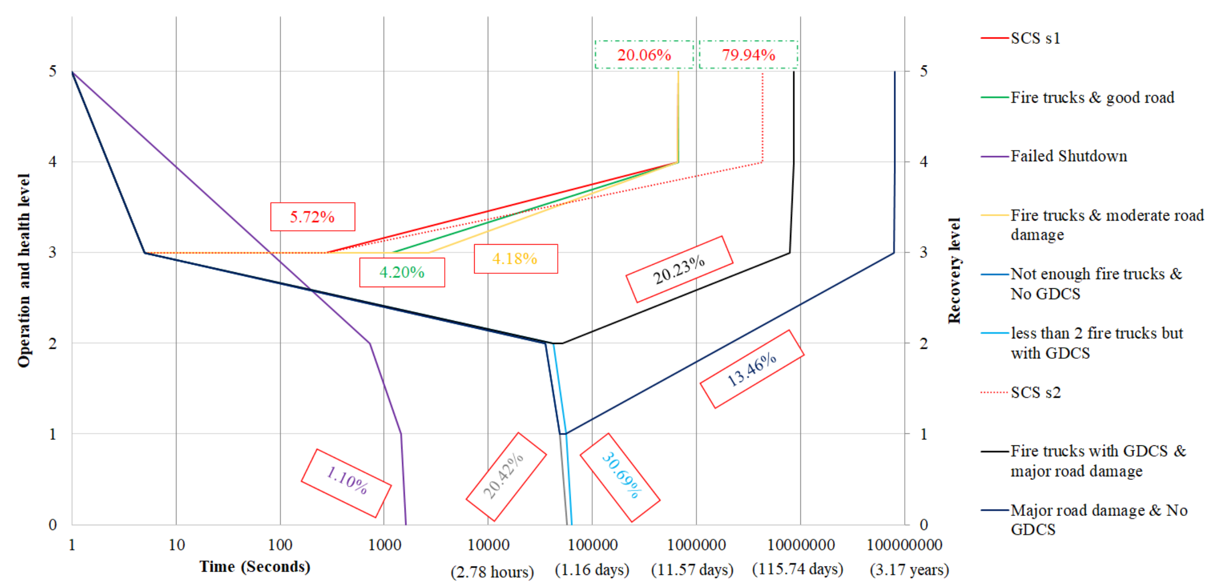
# External disruptive event – case study

- The event magnitude is assumed to be similar with **Fukushima** Daiichi nuclear disaster on 11th/03/2011.
- The impacts of the **earthquake, tsunami** and **flood** to the experimental CANDU reactor are considered.
- Only the power supply is considered.

| Subsystem(s) | Probability to be damaged |
|---|---|
| Offsite power | 100 % (earthquake, tsunami, and flood) |
| Onsite power | 100 % (reactor has to shut down due to safety issues after detecting the earthquake) |
| GDCS | 40% (assumed) |
| SDS1 | 5% (assumed) |
| SDS2 | 20% (assumed) |
| SCS | 70% (assumed) |
| Vacuum building | 20% (assumed) |
| SDG | 100% (tsunami and flood) |
| EDG | 92.3% (12 out of 13 failed) |
| Fire trucks | 20% (assumed) |
| Road | 10% no damage; 10% moderate damage; 80% major damage (assumed) |

# External disruptive event – case study

| Final status | Probability |
|---|---|
| Normal operation continued $P_N$ | 0% |
| Recovery within 12 days $P_{short}$ | 9.55% |
| Recovery longer than 12 days but shorter than 116 days $P_{mid}$ | 24.81% |
| Recovery longer than 116 days but shorter than 3.5 years $P_{long}$ | 13.46% |
| Reactor damage before recovery $P_{RD}$ | 33.70% |
| Core melt $P_{CM}$ | 52.18% |



# What's next

**Use the model to investigate the Impact of different factors on the resilience of reactor systems:**

- **Different external disruptive events** (e.g., earthquake, tsunamis, and hurricane)
- **More/less safety systems** (e.g., more fire trucks)
- **Different safety systems** (e.g., HPSIS with larger capacity)
- **Effectiveness of emergency response teams** (e.g., higher probability of emergency recovery, and less time to reach target locations)
- **Effectiveness of offsite supports** (e.g., shorter distance to the NPP)

**Automate the construction of the models from the operators/designers system description**

# Thank You