GENERATION

Designing for Safety trumps Operability

A Case Study at Sizewell B

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Lessons Learnt from Simulator Studies at Sizewell B

- SZB PSA Team (at Barnwood) got involved in 2009

- Classic (vanilla flavour) scenarios studies
  - SGTR, Bleed & Feed, Loss Of Offsite Power (LOOP)

- Study of LOOP with 2 out of 4 EDGs unavailable, run in 2011
  - Demanding on operators – Battery Charging DGs need local start

Burden on the Operators

- "We need to get an Op Tech out promptly on plant to do a CATS Reset before the compressors trip"

- Aim is to prevent an air pressure drop in the Clean Air Trains System (CATS)
  - otherwise the dump valve opens, and CATS depressurises

- All air-operated CATS valves go to fail-safe state
  - unless backed by the Nitrogen system

Lessons Learned (by SZB PSA Team)

- Talk to Operators and do scenario studies to find out:
  - What Operators actually do
  - What they perceive to be important (e.g. retain control of plant)
  - What else they have to do, as well as the Operator action in the PSA

Three Mile Island Control Room

T

Response by US Nuclear Industry following TMI

- Institute of Nuclear Power Operations set up in 1979 following Three Mile Island Accident
  - A recommendation in Kemeny Commission Report
  - An institute funded by nuclear utilities, but independent of them

- Its missions include
  - Promoting operational excellence
  - Improving Feedback of Operational Experience (OE) between US nuclear operators

US Nuclear Operational Experience (OE)

- A lot of OE in 1970s (and 1980s) was on instrument air, and air operated valves
  - INPO SERs & SOERs
  - US NRC NUREGs & GLs
  - Nuclear Safety Advisory Centre (EPRI) reports

- Two main concerns:
  - Gradual declining air pressure
  - Contamination

Instrument Air Problems – Effect on Nuclear Plant

- Both concerns can put plant into an “unanalysable state”
- Gradual decline in air pressure: Can’t predict the sequence of valves moving to fail-safe state
  - Causes:
    - Compressor failures, or Electrical Board failures
- Contamination: valves stick or operate spuriously
  - Causes:
    - Moisture, Corrosion products, Oil, Hydrogen, Dessicant powder

Meanwhile, what was happening in the UK?

- Wedding of Charles and Diana – July 1981
  - After Vows Fluffed
  - Kettles turned on
  - A major grid system pick up

- Miners Strike 1984-1985
  - No major blackouts
  - Nuclear power helped

And in the UK Nuclear Industry…

- AGR's
  - Major delays in building and commissioning
  - Were failing to achieve their output design targets
- PWR technology transfer into the UK
  - Sizewell B public inquiry started 1982
    - with Frank Layfield as inspector
  - Inspector's 3,000 page report issued 1987
    - after record breaking inquiry

SZB Project is going to build to time and cost!

The UK PWR Designer’s Problem

- UK regulator (NII) reluctant to see numerical credit taken for qualitative improvements unless there is evidence:
  - US (LWR NPPs) or UK (CEGB) data?

- Argued by SZB Project that SZB’s “peer group” was the US PWRs

- Process used by SZB Project to consider “Design Implications” of (mainly US) Operational Experience

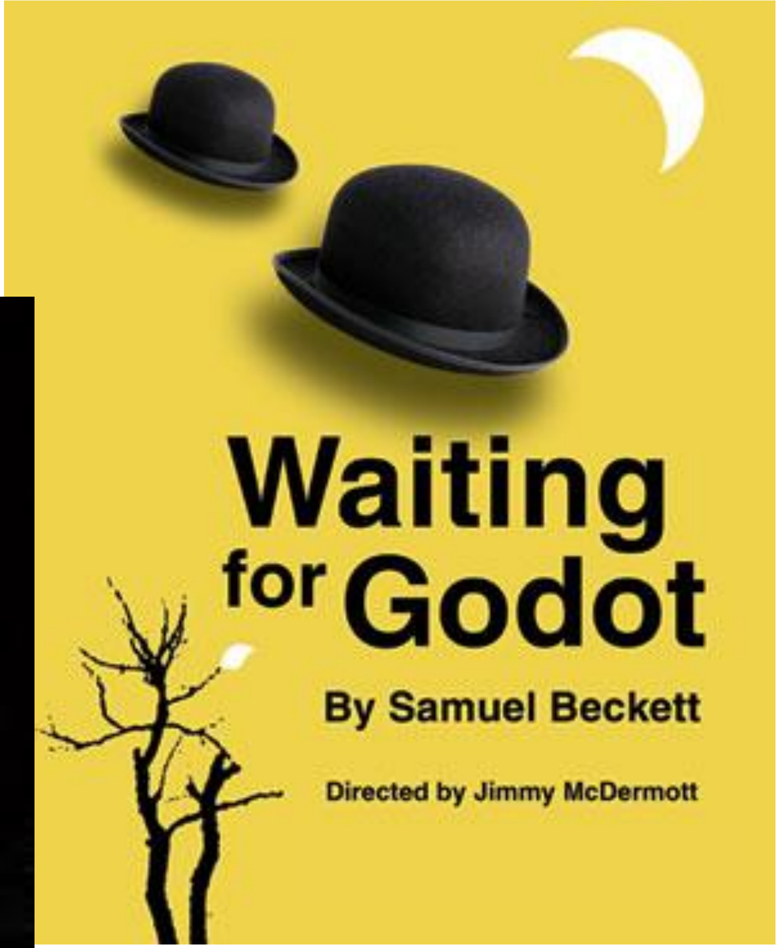
Common Mode Failure (CMF) Considerations

- “Edwards and Watson” UKAEA SRD 1979 Report: “A Study of CMFs”
  - Spawned various “Guidance” documents

- Resulted in stakeholder expectations (including NII)
  - Design should incorporate diversity systematically
  - System Cut-offs should limit reliability claims

Unless Operational Experience could justify better

- it usually couldn’t do at that time



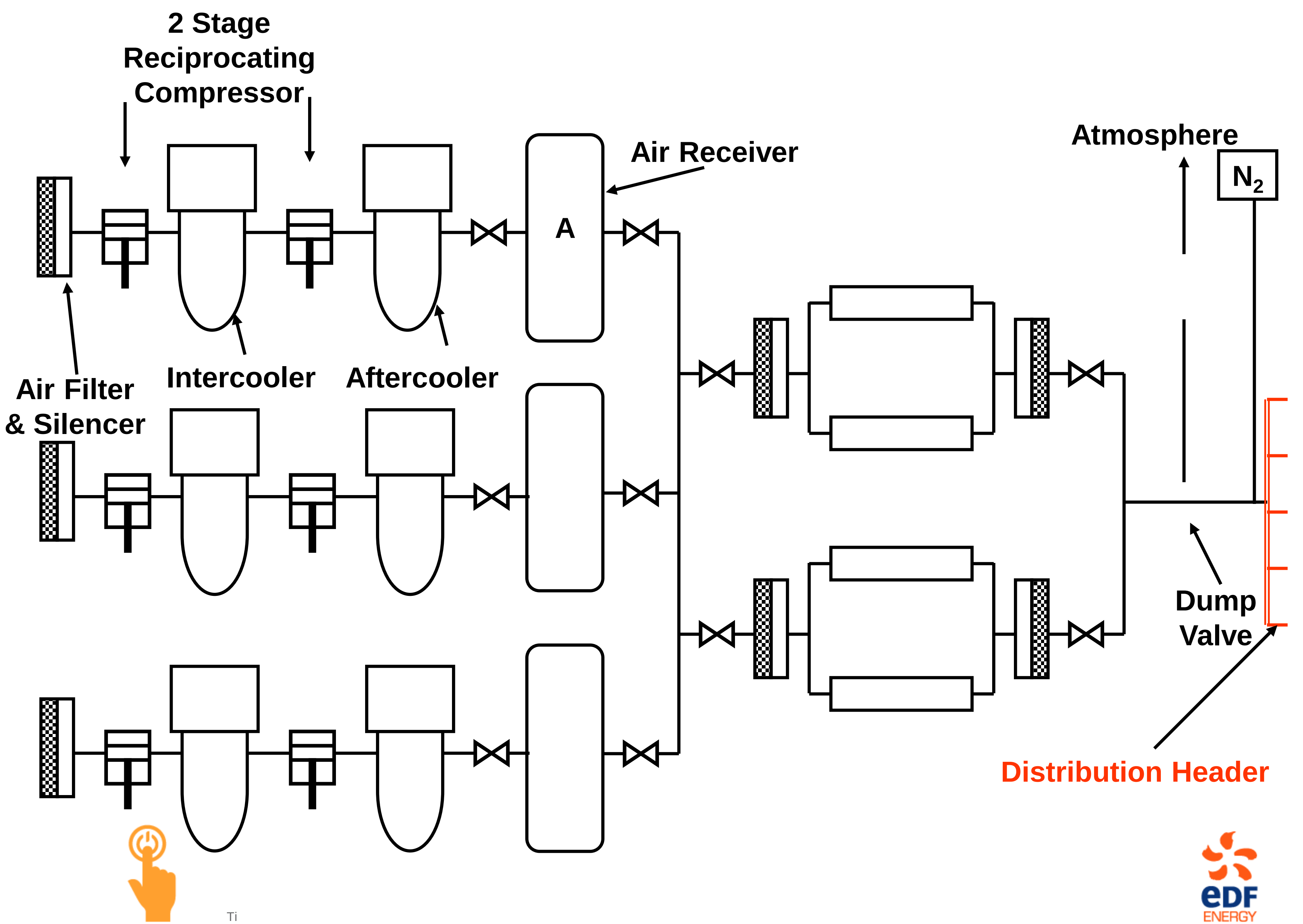
 Title of Presentation

Waiting for Consent

- SZB project finally got go ahead in 1987
  - and was “a more mature design”
- SZB design, compared with reference plant, now had some additional systems
  - EBS, ECS, RUHS, Double Containment
- Extensive changes within many systems
- Design used by Westinghouse and Nuclear Electric in joint bid in 1995 for Taiwan Lungmen plant
  - As met EPRI Advanced LWR requirements

Design Changes to the SZB Instrument Air System

- Selected nuclear safety-related air-operated valves segregated into a new system:
  - Those needed to achieve a safe shutdown state
- Clean Air Trains System
  - Two trains, three compressors in each train
  - Increased use of stainless and galvanised steel
  - Dump valves automatically open if air pressure falls below a preset value
  - CATS backed by Nitrogen system
    - so compressors not fed from essential boards


2 Stage
Reciprocating
Compressor
Air Receiver
A
Atmosphere
N_2
Air Filter
& Silencer
Intercooler
Aftercooler
Dump
Valve
Distribution Header

Diversity Rules? For SZB Air Systems

- Neither CATS nor Instrument Air System (IAS) were supplied by Essential Boards backed by EDGs
- Most LOOPs of short duration < 2 hours, beyond 24 hours very rare, so CATS is backed up by:
  - N2 system with accumulators
  - N2 Bottles as supplement for key valves
- But no back up for IAS
- Design robust for scenario of Station Black Out, a Design Basis fault for SZB, and enables use of essential control valves in a cooldown of primary circuit to RHR conditions

Low Pressure Nitrogen Storage Tanks

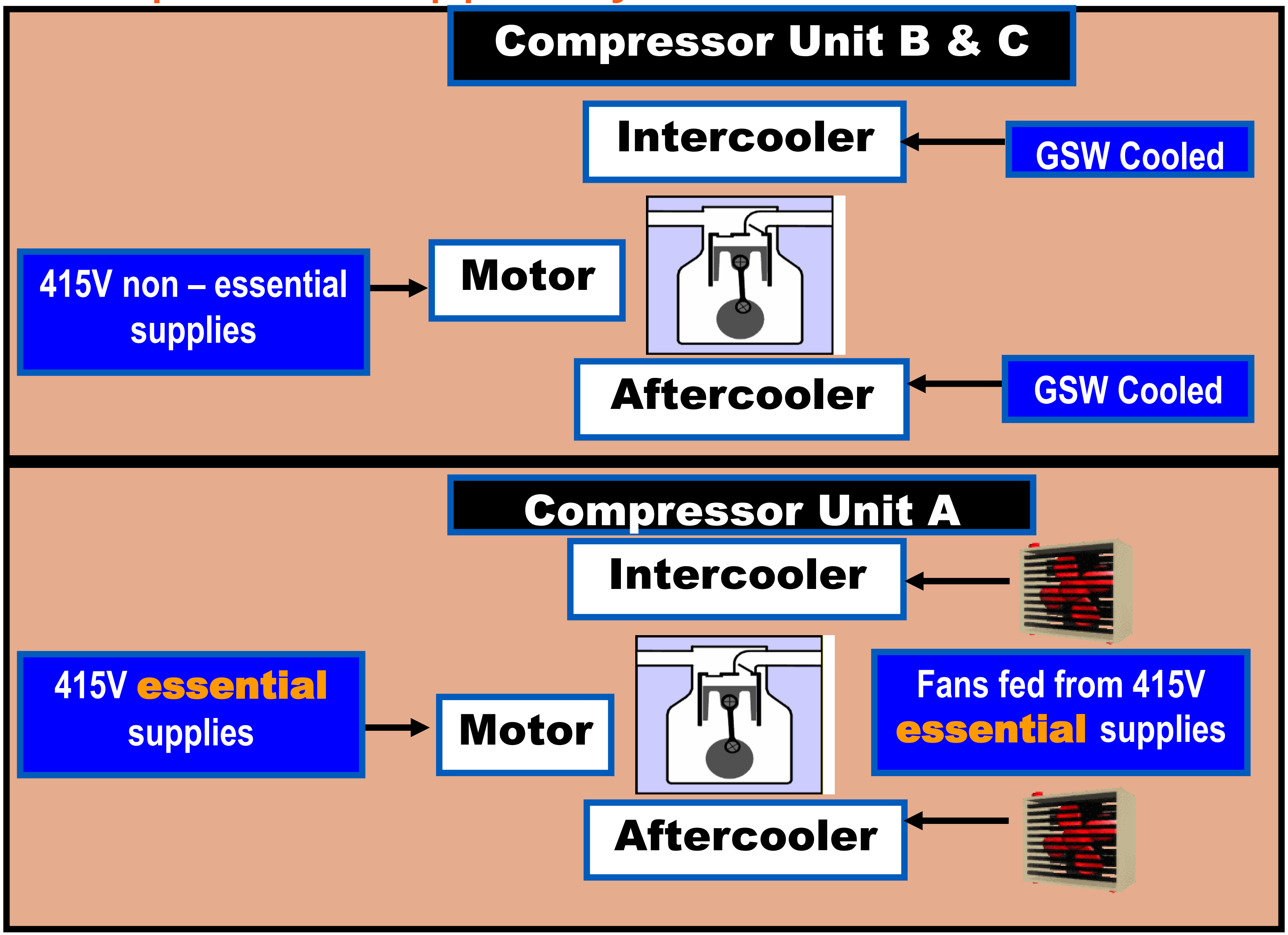
Lessons Learned during SZB Commissioning (1995) and Operation

- During commissioning trials CATS tripped 14 minutes into a “Loss of 11kV” test
  - Sequence of events resulted in a safety valve lifting
- In early winters a temporary diesel-powered compressor backed up IAS
- WANO SOER 1999-01 issued August 1999 on LOOP events
  - Reviewed OE on 25 safety significant LOOP events
  - Included an event at Hunterston B in December 1998
- Mandatory assessment of the SOER performed by SZB (and other UK NPPs)

SZB review of "WANO SOER on LOOP" - Outcome

- Operability after a LOOP needed improving
  - Reduce large burden on operators (MCR and Op Techs)
  - Prevent Pressuriser Relief Tank bursting discs from rupturing, resulting in primary fluid release into containment
- After optioneering, actions were agreed to
  - Replace one compressor in each CATS train with an air-cooled compressor so it did not depend on non-essential water cooling
  - This compressor to be fed from an essential board
  - Transfer some air operated valves, used by operators to retain control of primary circuit, from IAS to CATS

Compressor support systems after modification



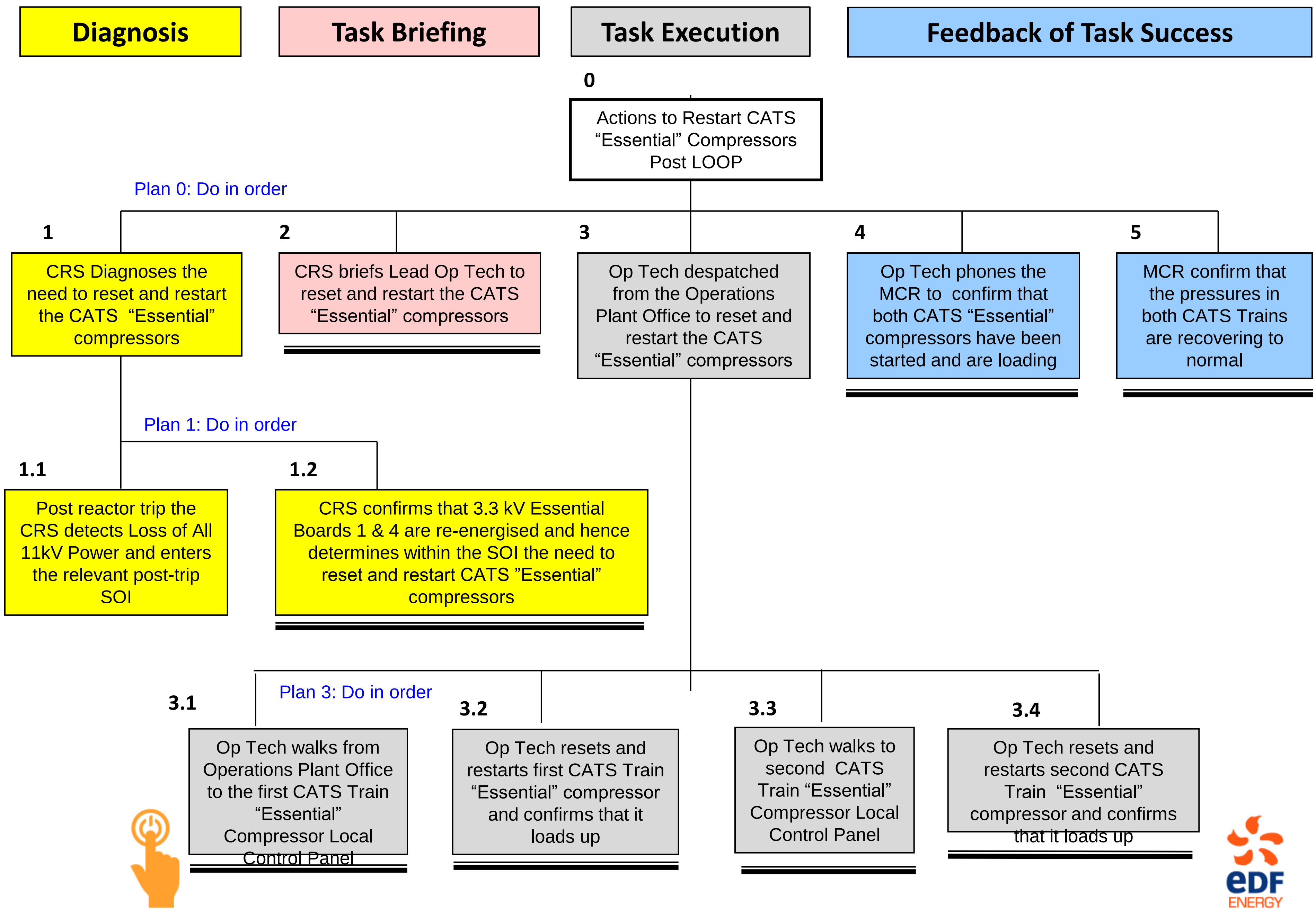
What followed next

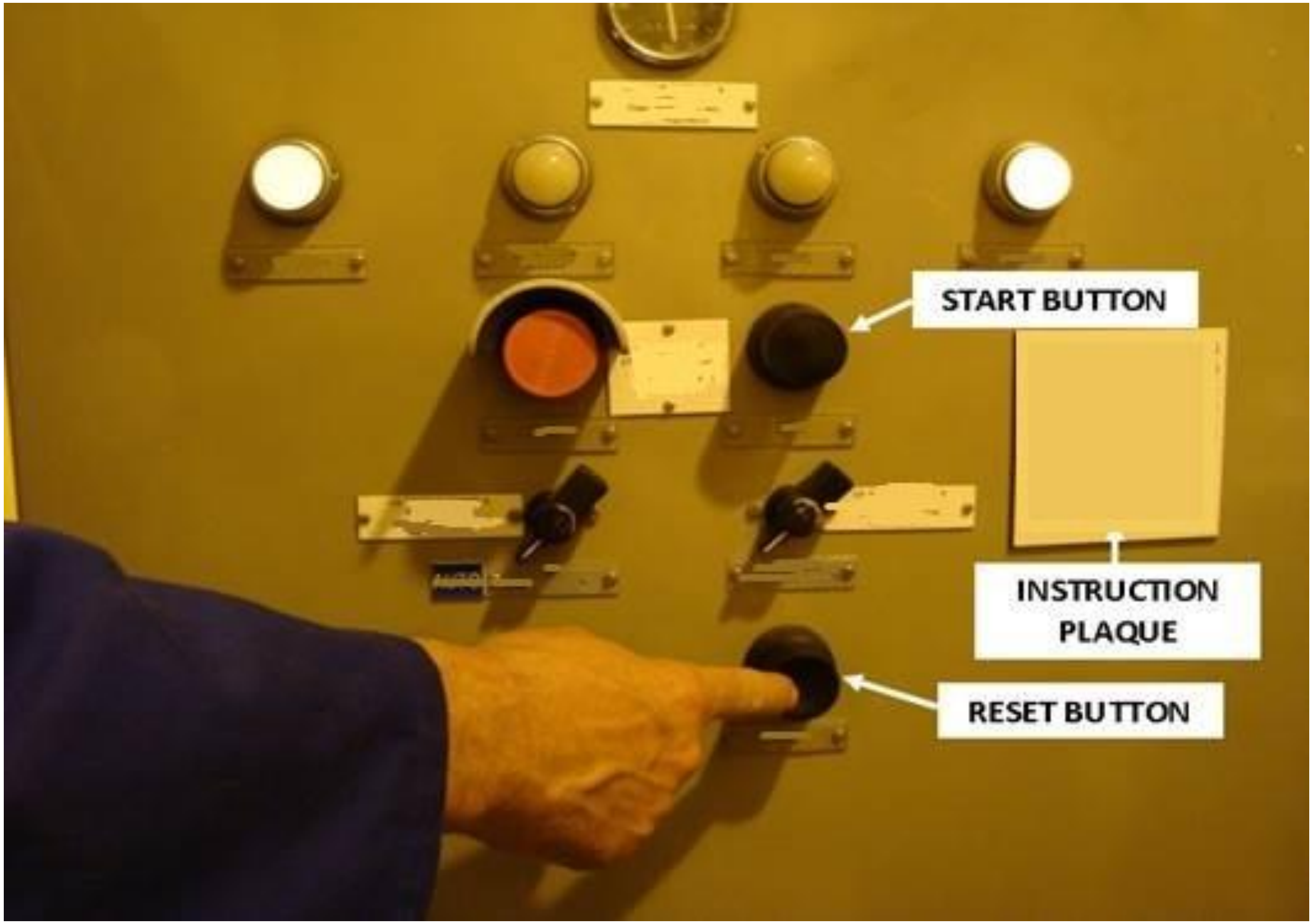
- Safety Category 2 Paper of Intent approved in 2004
  - Operability problems could be primary fluid released into containment
  - Considered to be a significant (but not serious) nuclear safety issue
- Programme of work initiated to modify plant, supported by Safety Case Staged Submissions
- Work overseen by Modification Implementation Meetings
- Work (including Ops handover and training) completed in RF07 (2005)

Now Move Forward to Simulator Studies in 2011

- Operators were aware of a local-to-plant CATS Reset
  - in SOI procedures after LOOP
  - but accepted that this was a design feature, despite the challenge it posed
- PSA team had modified Living PSA to take credit for one compressor in each train being fed by an essential board
  - But were not aware that the CATS compressors needed a Reset after a LOOP
- Requirement then arose to include the local to plant action in the Living PSA, and perform HRA to derive an HEP

Hierarchical Task Analysis: Restart CATS "Essential" Compressors Post LOOP





CATS Compressor Local Control Panel

HRA for performing CATS Reset (OSE61)

- First assessed by HEART in 2011: HEP = 0.07
  - But uncertainty over time available (20 minutes) to perform the action
- Then re-assessed using NARA in 2014: HEP = 1.0
  - 1995 Commissioning data:
    - Time to dump valve opening is <15 minutes
  - Simulator OPEX and plant walkdown:
    - Time required >15 minutes
  - Insufficient time => HEP = 1.0

Responding to the Finding

- Safety Case Anomaly raised
  - "Current design places an additional burden on the Op Techs with a high likelihood that they will fail in the task, impairing MCR control of RCS inventory and pressure"
- Review of station arrangements under SOER 1999-1 by a Shift Charge Engineer raised a Condition Report
  - CATS Compressors require a local reset after loss of 11kV. An "unsatisfactory" finding

=> Engineering Change Request raised in priority in 2014

Engineering the Change

- Modification made to the CATS compressors (one per train) supplied from Essential Boards to automate the reset:
  - Reduce the burden on the operator following a LOOP
  - Reduce the risk of a small spillage of reactor coolant to the reactor building
- Straight forward and inexpensive to engineer the change
  - Implementation completed in May 2016 during the last Refuelling Outage (RO14)

LOOP at Millstone in May 2014

- Loss of Instrument Air complicated recovery from a LOOP
  - The sustained loss of IA contributed to rupturing the Pressuriser Relief Tank bursting disc and discharging of 5,760 gallons of water into containment
- The likelihood of an event with similar consequences at SZB has been very much reduced

Response to WANO-SOER 1999-1: Before

- A key statement in the Paper of Intent:
  - [In the original design] “Each CATS train has a back up connection to the nitrogen system, but manual operation would be required for re-pressurisation of CATS”
- This statement is compatible with the original SZB safety case as:
  - Nitrogen system is the back up to CATS after a LOOP
  - CATS is only re-pressurised after Off-site supplies have been restored, and
  - the operators are in recovery mode, and there is no longer a nuclear safety threat

Response to WANO SOER 1999-1: After

- However in the new design:
  - The immediate backup for non nitrogen-backed valves is provided by resetting CATS following load shedding and reloading of the EDGs onto the Essential Boards
  - CATS reset is now required as part of the response to the LOOP, and before the CATS dump valves open
- A very different scenario to the “before” scenario, but the change was not identified in the proposed modification (Paper of Intent)

Human Factors and PSA Aspects

- Action in the "before" scenario was part of recovery from LOOP, not claimed by the LPSA
- In the "after" scenario, the operator action was:
  - Claimed in the LPSA, and graded as LOW,
  - Still needed assessing for feasibility as a local to plant action
- Grade is LOW as LPSA consequences are minor
  - but operators would be keen to avoid RCS spillage in containment

Nitrogen as back-up to CATS in original SZB design

- Benefit
  - Provided a robust defence against SBO
    - an infrequent threat to nuclear safety

- Drawback
  - Sole reliance on nitrogen impaired the response to LOOP
    - a frequent threat to operability and availability

The resolution has finally been achieved by automating the CATS reset operator action at the last outage

How was the Safety Case Anomaly identified?

- Pre-mod trials using simulator in 2001?
  - identified the need for the Operator Reset, but considered it to be consistent with the design
- Simulator studies in 2011
  - with participation of HF and PSA staff
  - but anomaly only raised after manual reset deemed infeasible
- Review of SZB's mandatory assessment of SOER 1999-1
  - provided independent support to raising mod priority

How might the anomaly have been prevented?

- Had there been a final report following the Paper of Intent and the Stage Submissions:
  - Was the design intent considered to have been met?
  - Has the burden on the operator been reduced?
- Early involvement of Human Factors, starting with the optioneering
  - Would need an understanding of how the change in scenario impacted a low-level plant feature
- Other suggestions are invited

Acknowledgements

- Various skilled staff have helped to make this presentation possible
  - Simulator Tutors
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  - PSA and HF Engineers
  - Ex SZB Project Engineers

THANK YOU

Any Questions?

Memo pre Three Mile Island Accident