Hazards and operability study of the chemical injection system of the UK European Pressurised Reactor

Mersiha Rozic, Systems Engineer, Electricité de France – Generation and Engineering Branch – CNEPE, 8, Rue de Boutteville, BP 0437, 37204 Tours Cedex 3, France, mersiha.rozic@edf.fr

The UK European Pressurised Reactor (EPR) is the latest generation of French pressurised water nuclear reactor designs, one of which is currently being built at Flamanville 3 in France with two others planned for construction in the UK (Hinkley Point C, Somerset) in the years to come. The UK EPR Project has received the European Commission approval on 8th October 2014.

The UK EPR reactor unit, able to generate 1650MWe, is predominantly inspired from the Flamanville 3 basic design. Depending on similarities and differences between Flamanville 3 and UK EPR systems, a number of reviews and engineering studies based on the French EPR design have been implemented with the aim to:

- Allow project adaptability to the UK context and British legislations for the systems which did not have to undergo significant modifications compared to the Flamanville 3 design,
- Consolidate security, operability, maintenance arrangements, costs and efficiency features for systems that had to be substantially modified compared to the French EPR design.

EPR Chemical Injection System, named SIR (Système d'Injection de Réactifs) has for role to ensure chemical unloading, storage, preparation and injection into nuclear plant secondary circuit and its primary and secondary auxiliaries. Chemicals injected by the SIR system are hydrazine, morpholine or ethanolamine, ammonia and trisodium phosphate.

Specific hazards related to the chemicals (hydrazine being carcinogenic, ammonia explosive and morpholine flammable) were to be considered in the SIR design. In addition to use of dangerous and toxic products, notable modifications of the Flamanville 3 SIR system have been introduced in the UK EPR design. This was mainly the case of the hydrazine storage and unloading zone that had to be accommodated to the UK hydrazine supply chain. As a matter of fact, in France hydrazine is supplied in 200 L barrels and in 55% hydrazine hydrate mass concentration, whereas on the UK EPR, diluted hydrazine (below 5% hydrazine mass) will be delivered on site in road tankers.

As such, on account of the presence and use of dangerous chemicals within the system and in regards with major changes in hydrazine unloading and storage area between French and British designs, a decision to carry out a Hazard and Operability study had been taken in order to ensure thorough review of SIR process functions, operability features and security arrangements. The HAZOP review was conducted in May 2012 at CNEPE, the EDF Conventional Island Engineering and Generation Branch, in Tours, France, and resulted in system's improvements, process operability optimisations and maintenance enhancements.

The HAZOP multi-disciplinary team was composed of experienced French and British chemical and process engineers, industrial safety engineers, former SIR plant operator and chemists. In the HAZOP review, this team of eight process specialists was brought together over three days and analysed in depth, node by node, each process hazard that could appear through daily system operations. In addition to this, chemicals incompatibility within the system was also analysed.

As such, the HAZOP review resulted in a list of 94 actions and check-ups that were drawn up through the review of 53 process nodes. Following the review, system design modifications were implemented within the UK EPR SIR system technical specifications to be taken into account by the future SIR constructor.

The HAZOP review was audiorecorded in addition to written records of a HAZOP scribe.

The operating experience of the SIR systems of the 58 EDF French nuclear reactors has also been researched and put into consideration of the HAZOP team. This aimed to point out process operation difficulties and issues that have been encountered on similar processes.

The conclusions of the SIR system HAZOP safety review were presented in several EPR safety and operation meetings where the review was received with large interest and enthusiasm and served as great example of good engineering practice for the nuclear industry.

Keywords : European Pressurised Reactor (EPR), nuclear, SIR system, chemical injection, Hazard and Operability (HAZOP), review, hydrazine, action, modification.

Introduction

The UK European Pressurised Reactor (EPR) is the latest generation of French pressurised water nuclear reactor designs, one of which is currently being built at Flamanville 3 in France. Two others of the kind are planned for construction in the UK (Hinkley Point C, Somerset) in the years to come after having received the European Commission approval on 8th October 2014.

The UK EPR reactor unit, able to generate 1650MWe, is predominantly inspired from the Flamanville 3 basic design. Depending on similarities and differences between Flamanville 3 and UK EPR systems, a number of reviews and engineering studies based on the French EPR design have been implemented with the aim to:

- Allow project adaptability to the UK context and British legislations for the systems which did not have to undergo significant modifications compared to the Flamanville 3 design,
- Consolidate security, operability, maintenance arrangements, costs and efficiency features for systems that had to be substantially modified compared to the French EPR design.

One of the UK EPR systems having undergone safety review was the Chemical Injection System – SIR (Système d'Injection de Réactifs). The SIR system role is to ensure hydrazine, morpholine or ethanolamine, ammonia and trisodium phosphate injection into secondary circuit, steam generators and primary and secondary auxiliary systems of the nuclear plant, in an effort to maintain a reducing environment and mitigate corrosion while on power and at shutdown.

In order to ensure a thorough review of SIR process functions, operability features and security arrangements, a Hazard and Operability study was conducted in May 2012 at CNEPE (Centre National d'Equipement de Production d'Electricité), the EDF Conventional Island Engineering and Generation Branch, in Tours, France, and resulted in system process improvements, operability optimisations and maintenance enhancements.

The study is carried out based on the normal operation of the system whilst the nuclear power plant is on power and during outages, when the SIR system is used for steam generators wet lay-up.

1. Differences in French and United Kingdom hydrazine supply, storage and unloading strategies

Hydrazine, N_2H_4, is an inorganic, toxic, dangerous for the environment and carcinogenic compound, widely used within both primary and secondary nuclear power plant cycles to control concentrations of dissolved oxygen in an effort to maintain a reducing environment and reduce corrosion.

Across the French fleet, hydrazine is delivered on site as 55% weight concentrated hydrazine hydrate form (35% weight hydrazine) and in 200kg barrels which are stored prior to mechanical unloading. Once unloaded in the SIR preparation tanks, hydrazine is diluted to reach concentration below 5% weight in final solution, which is then injected into the secondary circuit and auxiliaries.

On the UK EPR, a substantially different choice has been made for hydrazine supply: hydrazine is to be delivered on site already diluted below 5% weight, transported by road tankers. Hydrazine will then undergo unloading into the hydrazine site storage tank through the unloading pump being part of the delivery tanker.

2. SIR System location and outline

2.1. SIR System location

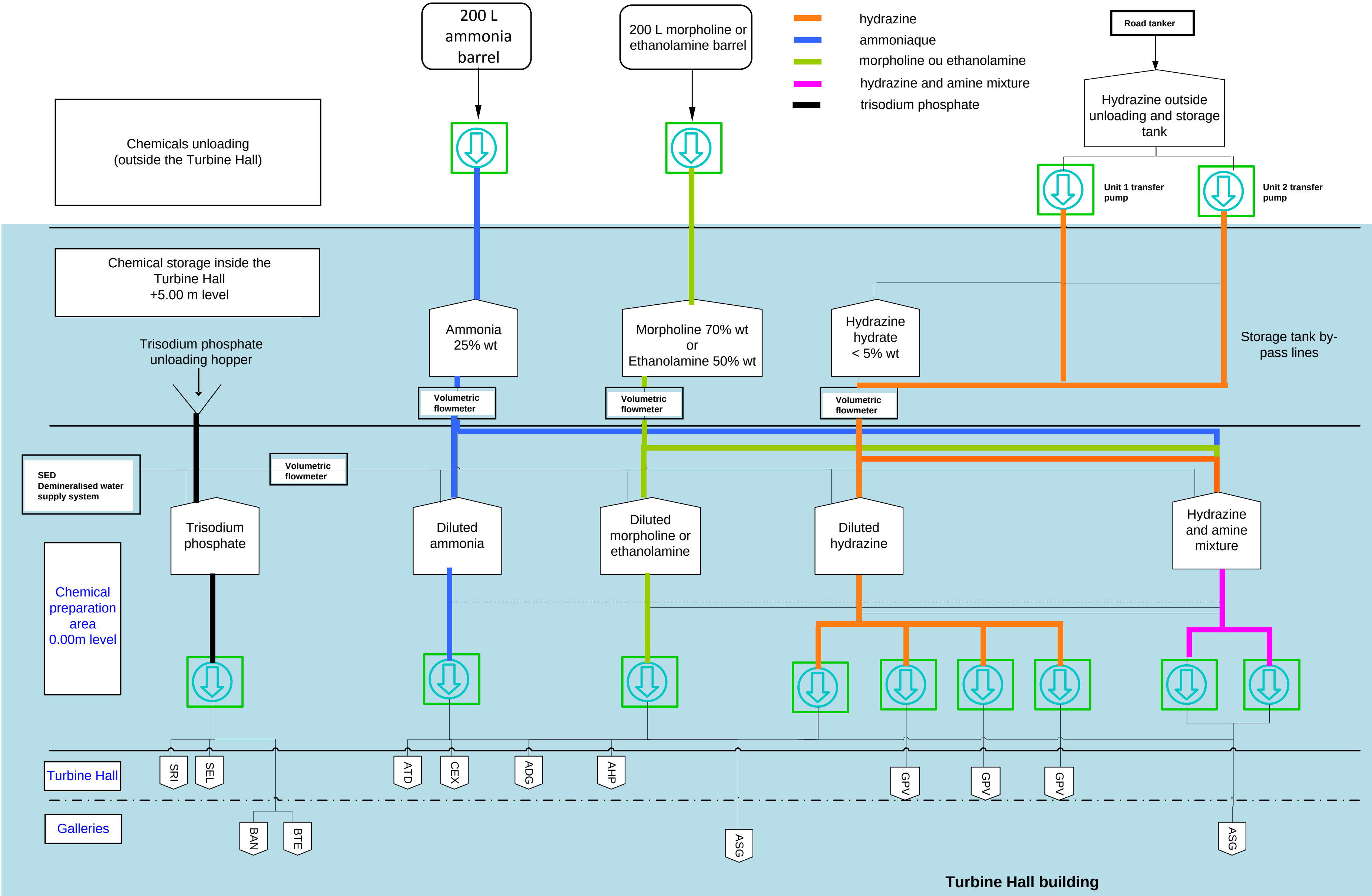
The SIR Chemical Injection System consists of:

- Outside hydrazine unloading area away from the Turbine Hall, shared between two EPR units,
- Morpholine or Ethanolamine and Ammonia unloading area located outside the Turbine Hall at +5.00m level,
- Indoors hydrazine, morpholine or ethanolamine and ammonia storage area, located at level 0.00 m of the Turbine Hall,
- All reagents preparation and injection area, located at -5.00 m level of the Turbine Hall.

The hydrazine unloading area is common to both units, whereas the three other areas are specific to each unit.

2.2. SIR System outline

A schematic representation of the UK EPR SIR system is given in figure 1.



ADG : Feedwater de-aerator tank
AHP : High Pressure feedwater system
ASG : Back-up feedwater system
ATD: Secondary circuit water purification system
BAN: Nuclear auxiliaries building
BTE: Effluents treatment building
CEX : Condensate extraction system
GPV: Main vapour circuits and purge
SED: Demineralised water supply system
SEL: Hot water electrically heated
SRI: Intermediary cooling for conventional island

Figure 1 : UK EPR SIR System fonctional diagram

3. Boundaries, scope and purpose of the Hazard and Operability Review

3.1. Scope of the SIR System HAZOP Review

The scope of the review comprised all operating steps for the chemical unloading, storage, preparation and injection of chemicals and included analysis of five chemical reagents considered for the future Hinkley Point C chemical conditioning: hydrazine, ethanolamine, ammonia and trisodium phosphate. The compatibility of chemicals had been considered as well to identify potentially hazardous mixtures that can occur in the injection pipelines.

3.2. Aims of the SIR System HAZOP Review

The aims of the Hazard and Operability study carried out on the UK EPR SIR chemical injection system were to:

- Examine system design regarding security of station personnel and chemists in usual operations of unloading, storage, preparation and injection of chemicals; meanwhile ensure installation conformity in regards to Health and Safety legislations, norms and Work Act requirements, especially in relation to carcinogenic reagents. In case of gaps or misses identified during the review, the aim was to propose modification of existing equipment or addition of new equipment in order to eradicate risks and mitigate consequences,
- Analyse the systems safety regarding risks relating to dangerous chemicals (ATEX risk due to ammonia), and also, related to equipment operation and possible malfunctions,
- Verify the optimum design of the installation in relation with natural effluent management (rain water) and those resulting from systems operations or chemical discharge,
- Recommend organisationnal features in terms of operations with purpose to guarantee and reinforce personnel security and allow safe and reliable operation, e.g. in the matter of alarms treatment and management or in chemical preparations operating procedures etc.

3.3. SIR System boundaries for the HAZOP review

The system boundaries considered at the review were defined as follows:

- For morpholine or ethanolamine and ammonia unloading: 200L barrels (included), connected for unloading in the retention zones of the Morpholine or Ethanolamine and Ammonia unloading area,
- For hydrazine unloading: tank truck delivering hydrazine hydrate solution (included),
- For commercial solution storage: stainless steel tanks with their instrumentation devices and connections to the auxiliary fluids,
- For chemical preparation: stainless steel preparation tanks with their instrumentation devices and connections to the auxiliary fluids.
- For chemical injection: injection pumps up to the downstream injection points into the secondary circuit pipelines (ADG, AHP, ASG, ATD, CEX, GPV, SEL, SRI[1]) including the injection nozzles. The limit of the SIR system in relation to the serviced system is located at check valve and isolation valve of the conditioned circuit.

[1] For system acronyms significations, report to Figure 1.

4. Operating and Design Experience taken out from the French nuclear fleet SIR systems operation

Some relevant Operating Experience (OpEx) regarding the SIR system operation and maintenance is presented in the table 1. This OpEx comes from the French fleet stations built in the 1970s and the 1980s, whose design differs from the EPR SIR design.

Materials affected	Across the French fleet	On the UK EPR
Secure transfer system connectors	Fragile. They have limited resistance to repetitive shocks (fatigue) occurring while connecting and disconnecting the barrels.	Secure transfer system scheduled. Appropriate training to be delivered to personnel with caution brought to material fatigue.
Unloading pumps	Some of French unloading pumps are of peristaltic technology, where the liquid is pumped though a flexible pipe by a roller press. A possible rupture of flexible rubber pipe may cause leakages.	On UK SIR, the unloading pumps will be of pneumatic double diaphragm technology. The pumps will be instrument air driven and the double diaphragm will confine the reagent inside the pumping system, allowing no leaks.
Preparation tanks	Overflowing of preparation tanks (morpholine, ammonia and phosphate) occurred sometimes.	Both water and reagents admission valves on the UK SIR are scheduled to be automatic, with closed fail safe position. Tanks will be equipped with level measurements controlling the automation system interface.
Injection pumps	Some leakages occurred, due to the pump design that differs from the one intended for the UK SIR pumping system. On the French fleet itself, injection pumps are currently being replaced by double diaphragm pumps.	The UK SIR will be equipped with double diaphragm technology with diaphragm rupture control by pressure detector.
Injection nozzles	Leaks and blockages of injection nozzles happened.	The EPR injection nozzles scheduled are to be able to be disassembled both in outages and when the reactor is on load to be cleaned so that to avoid blockages.

Table 1: Operating and design experience features from the French fleet SIR systems

5. SIR system HAZOP review

UK SIR Hazop review took place on 14th, 15th and 16th May 2012 at CNEPE (Centre National d'Equipement de Production d'Electricité, Tours, France) and had for aim to investigate the design features that require further study or system characteristics and technical specification update of the relating plant equipment to be supplied, delivered and put into place by the future contractor.

5.1. HAZOP review panel

The review was carried out by a multi-disciplinary team of process and safety engineers, coming from both French EDF sites and engineering branches, but also from Nuclear New Built (NNB) in charge of the UK EPR Project in the UK.

HAZOP team members	Role
M.SPAHIC (M.ROZIC)	HAZOP chairman and process engineer
K.EADE	UK EPR SIR system engineer and HAZOP scribe
M.ALVES-VIEIRA	EDF Chemist
P.BONNET	Former SIR plant operator and system engineer
K.LAUWEREINS	Process engineer specialised in industrial safety
M.AKPOBASAH	NNB Process engineer on assignment at EDF France
A.COOPER	NNB Chemist on assignment in the Chemistry department at Sizewell B nuclear power station (Suffolk)
C.MINARET	Industrial safety engineer and manager

Table 2: Composition of the HAZOP multi-disciplinary team

5.2. HAZOP review on the hydrazine unloading and outside storage zone

Because of a considerably broad review carried on the entirety of the SIR system (53 nodes were examined, 94 actions were recorded), it has been chosen in this paper to present the HAZOP nodes, findings and actions relating to the hydrazine unloading and storage area, in which lies the main difference between French and UK EPR designs.

The Figure below represents the nodes positions of the SIR hydrazine unloading and outside storage sub-system.

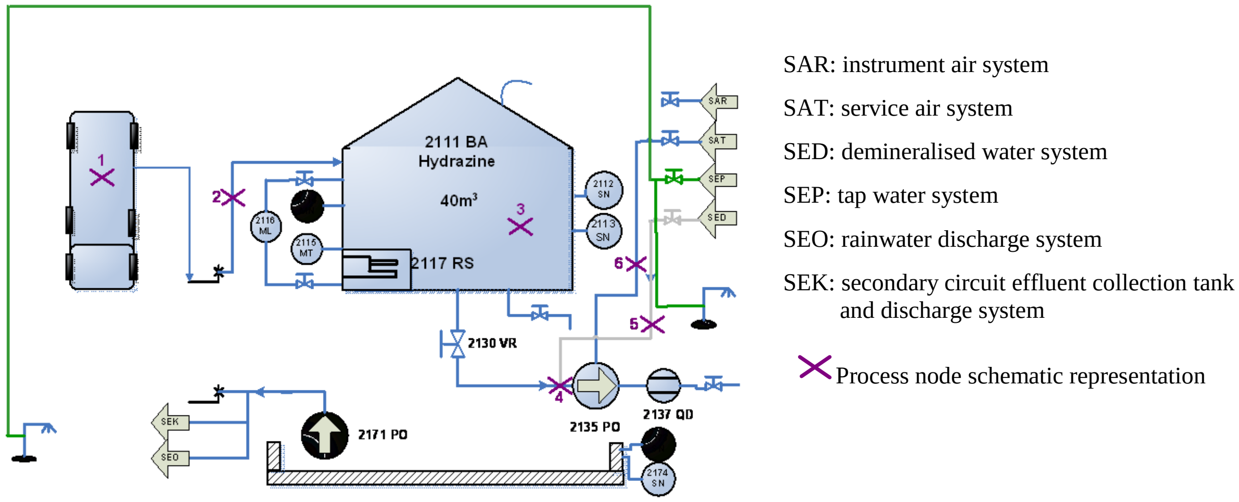


Figure 2: SIR system hydrazine unloading and storage envisaged for the UK EPR reactor

5.3. HAZOP review on chemicals incompatibility

On account of dangerous and harmful chemicals used within the SIR system, the HAZOP review also examined the incompatibility of hydrazine, ammonia, morpholine or ethanolamine and trisodium phosphate.

6. SIR System HAZOP examination and actions

Actions resulting from the review have for aim to amend and adjust the initial design of the system so that to eradicate hazards and mitigate consequences. The major actions have been classified under categories below:

- Mitigation of risks to operating personnel,
- Environmental discharge management,
- Operability and ergonomics of plant,
- Maintenance,
- Procedural and organisational actions,
- Incompatibility of chemicals.

The major part of the actions is related to the hydrazine unloading operation, which represents the major difference with the Flamanville 3 SIR design. The delivery by road tanker is not commonly employed in France for the delivery of hydrazine. This is the reason why the road tanker connection and unloading operations broadly interested the HAZOP team and were analysed in depth. This thorough analysis led to a number of actions and questions, presented below.

The HAZOP review actions focused on operating staff industrial safety and environmental discharge management due to use of dangerous chemicals (carcinogenic hydrazine, explosive ammonia, inflammable morpholine etc). Chemists and operators from the panel also reviewed plant ergonomics, operability and maintenance.

6.1. Mitigation of risks to operating personnel

The HAZOP actions in regards with the risks to personnel were mostly related to the connection and safety arrangements of the road tanker to the unloading area.

HAZOP questions raised at the examination of nodes 1 and 2

1. Road tanker pump design :
   - What is the pump type?
   - Is a non-return valve included within the tanker downstream the pump?
2. Is the sampling of the tank possible?
3. What are the UK transport regulations? Is repatriation of hydrazine back to supplier possible in the case there is not enough space in the storage tank?
4. Hydrazine pump to pipe connectors: is there a unique color and size?
5. How to manage disposal of residual hydrazine from the flexible pipe connection?
6. Investigate need for trace heating of the connection line from hose to the rigid pipework.

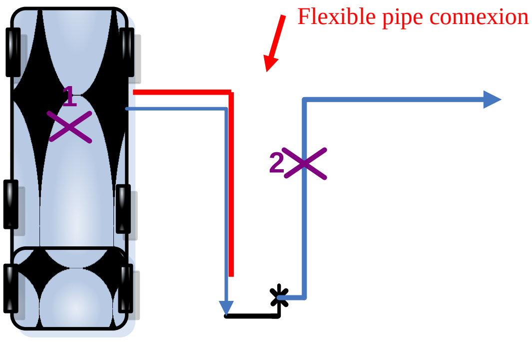


Figure 3: Representation of nodes 1 and 2 of the HAZOP review

Follow-up actions from the review of nodes 1 and 2:

1. Little control over suppliers' lorry and pump. Lorry equipped with a pressure relief valve set at 7 bar.
2. Tank sampling possible.
3. No hydrazine to be left in the tank after unloading. Regulations do not allow repatriation of hydrazine.
4. No unique size nor specific connector available. Red color scheduled for hydrazine unloading.
5. The unloading procedure is to contain rules of conduct for disposal of residual hydrazine remaining in the flexible pipe.
6. No need for trace heating between the lorry and the tank: insufficient time of the unloading operation to allow freezing.

6.2. Enhanced environmental discharge management and maintenance considerations

A number of actions concern the management of discharges to the environment and aimed at reducing waste and volumes of hydrazine going to bunds.

HAZOP questions raised at the examination of node 3

7. Is there a need to measure the flow lost through the storage tank overflow pipe?
   - For enhanced effluent control?
   - For purposes of monitoring of discharged volumes of hydrazine?
8. Is there a need to add a very high sensor onto the storage tank? (the operating experience on French reactors shows number of important overflows on SIR tanks).
9. Overflow off-take pipe to be scheduled at the very high tank level.
10. Check the tank vent is below the input pipe to avoid vapor suction.
11. Investigate need for trace heating of the vent.
12. Make sure the 2130 VR valve is motorized and automatically driven by the automation system. This is to allow accurate preparation of diluted solutions and avoid unnecessary effluents.
13. Investigate need for a sampling tap with a double isolation valve.
14. Where does the SED water from the pipe rinsing goes to? Into the storage tank?
15. Verify valve on line with SEO. Isolation valve is required.
16. Verify valve on like with SEK. Isolation valve is required.
17. Check a manhole is scheduled on storage tank (required for maintenance and inspection).
18. Verify the out-take pipe off-take is not at the very bottom of the tank, so that to avoid pumping impurities.

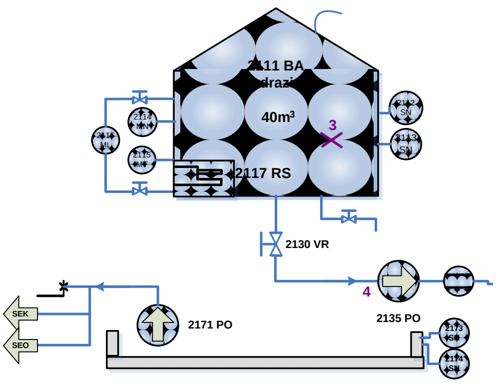


Figure 4: Representation of nodes 3 of the HAZOP review

Follow-up actions:

7. No need for effluent measurement at this point
8. Very high level alarm to be added in storage tank technical specifications.
9. Technical specifications amended to schedule the overflow off-take pipe at the very high tank level.
10. Technical specifications modified in accordance.
11. Trace heating added to the technical specifications of the unloading tank vent.
12. The 2130 VR valve is motorized. No change to be made to the specifications.
13. Sampling tap with double isolation valve added to the specifications.
14. The demineralised water is to be evacuated to the SEK secondary effluents collection tank. Specifications updated.
15. Isolation valve on SEO line added to the specifications.
16. Isolation valve on SEK line added to the specifications.
17. Manhole already scheduled. No change in specifications.
18. This point is to be checked in detailed design studies and has been recorded for contract surveillance purposes.

6.3. Operability of equipment, plant ergonomics and procedural arrangements

HAZOP questions raised at the examination of node 4

19. What happens if the tank is simultaneously being emptied by transfer to the hydrazine preparation tank in the turbine hall and filled up through an unloading operation?
    - Is the SIR automation system able to regulate levels and flows in and out of the tank while these 2 operations are taking place simultaneously?
    - Is this safe and does this allow overflow prevention?
20. Are the valves located outside always easily operable? What about cold winter periods? Will the operator be able to open / close them?
21. Are all the valves lockable?
22. Verify the out-take pipe off-take is not at the very bottom of the tank, so that to avoid pumping impurities.
23. Is the tap water feed to safety showers guaranteed in any season? What about cold winter periods?
24. Would hydrazine pumping out through the 2135 PO pump be stopped at low level in the storage tank?

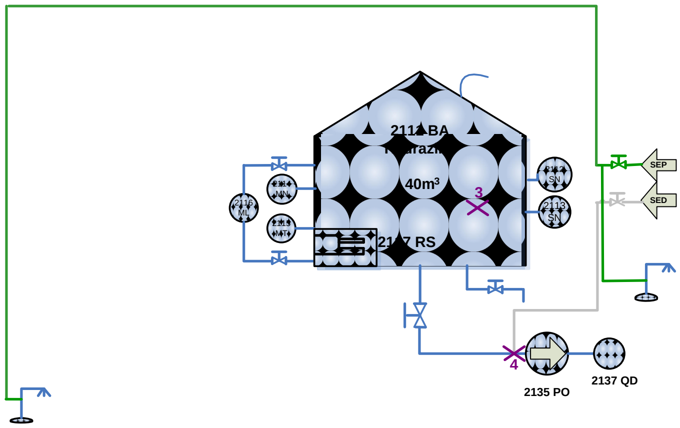


Figure 5: Representation of node 4 of the HAZOP review

Follow-up actions:

19. The SIR automation system does not have the possibility to monitor tank level while simultaneously emptied and filled up. It is considered unsafe to allow unloading and preparation of hydrazine at the same time. A safeguard has to be implemented within the automation system program that will lock and unable simultaneous filling and emptying of the tank.
20. In severe winter periods, there is a risk for the valves' operability. Specifically qualified and tested valves for outside conditions are to be scheduled within the SIR contract. This is an important point for future contract surveillance to be followed and checked with the future contractor.
21. The contract specifications are to request specifically lockable valves. This is scheduled within SIR technical specifications.
22. The out-take pipe off-take position is to be checked through the detailed design studies with the chosen contractor. This point has been marked as important for surveillance.
23. Outside pipework is to be trace-heated.
24. The 2135 PO pump is to be equipped with a safeguard that allows it to stop pumping as soon as the low level in the tank has been detected. This has been included in SIR contract technical specifications.

6.4. Incompatibility of chemicals

The HAZOP team panel examined possible chemical reactions (Table 3) that could possibly take place when the reagents present within the SIR system get in contact with themselves, air or water. The chemical incompatibility matrix was also drawn up as shown on Figure 6.

Regarding chemical reactions that could possibly take place in the SIR system, the HAZOP review put into light the fact that each reactant under its concentrated form has its entirely separate and dedicated pipeline. Hence, the risk of getting a reaction between concentrated chemicals is excluded. In addition to this, the mixture of chemicals, for steam generators wet lay-up purposes, is composed of diluted solutions of hydrazine, morpholine or ethanolamine and ammonia. Wet lay-up operations are carried out on infrequent basis (approximately every 18 months) and they also have a limited duration: they are injected into the steam generators as soon as they are prepared. Thus, the risks of chemical incompatibility within the diluted mixture are limited.

Therefore, hydrazine, morpholine or ethanolamine and ammonia mixtures do not present any chemical hazard. However, hydrazine being carcinogenic, morpholine corrosive and flammable, ethanolamine corrosive and ammonia explosive, the HAZOP review has considered the intrinsic hazards of these chemicals and as such, suitable equipment for hazard mitigation or eradication has been scheduled:

- Hydrazine is to be operated in a sealed and leak-proof system: the HAZOP examination and actions made sure this was appropriately scheduled,
- Ammonia is to be handled in the ATEX classified equipment: the HAZOP team panel made sure this is implemented accordingly,

- Morpholine and ethanolamine present classical industrial hazard: morpholine flash point had been investigated and conclusion had been drawn up that no hazard is to be mitigated at SIR operating temperature,
- Trisodium phosphate will not undergo mixing with other chemicals. No incompatibility issues are to be examined. The HAZOP analysis focused on its solubilisation in water (preparation for the circuit conditioning injection).

In regards with chemical mixtures, the HAZOP review had concluded that the SIR system design was sufficient to prevent dangerous mixtures of reactants. In point of fact:

- All tank vents have their separate pipelines,
- Chemical bunds (retentions) of each reactant are separate and independent,
- Mixtures implemented in the SIR system are prepared from diluted chemical solutions and on infrequent and short-duration basis. This satisfactorily mitigates the hazards of chemical reaction within the mixture.

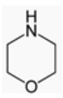
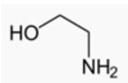
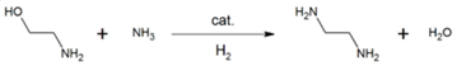
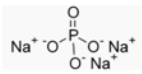
Hydrazine N_2H_4 2.5 or 5% wt	$3\,N_2H_4 \rightarrow 4\,NH_3 + N_2$. $N_2H_4 \rightarrow N_2 + 2\,H_2$. For T > 120°C
Morpholine 70% wt 	Reacts with the nitriles in aqueous solutions to form N-nitrosomorpholine $C_4H_8N_2O_2$ but no reaction at pH > 7 $C_4H_9NO + HNO_2 \rightarrow C_4H_8N_2O_2 + H_2O$
Ethanolamine 50% wt 	
Ammonia NH_3/NH_4OH 20-35% wt	$NH_3 + H_2O \rightleftarrows NH_4^+ + HO^-$ $2(NH_4^+ + HO^-) + CO_2 \rightarrow (2NH_4^+ + CO_3^{2-}) + H_2O$
Trisodium phosphate 	$Na_3PO_4 + H_2O \dashrightarrow NaOH + Na_2HPO_4$. $H_2CO_3 + 2\,NaOH \dashrightarrow Na_2CO_3 + 2\,H_2O$ ou : $CO_2 + 2\,NaOH \dashrightarrow Na_2CO_3 + H_2O$ In presence of carbonic acid H_2CO_3 (CO_2 dissolution in water) Precipitation at low T : $3\,Na^+ + PO_4^{3-} \rightarrow Na_3PO_4$ (s)

Table 3: Possible chemical reactions within the SIR system

In addition to this, the incompatibility matrix had also been constructed at the HAZOP review by the multidisciplinary panel. This was done by confronting chemical dangers of each reactant and by identifying them in the chemical matrix of dangers. This is shown in Figure 6.

Because of all chemicals being of a similar chemical nature, all of them being amine and basis compounds, they do not react among themselves, especially not at the SIR system operating temperature (ambient). As such, their toxic, corrosive and flammable characteristics do not present any credible hazard in the SIR process.

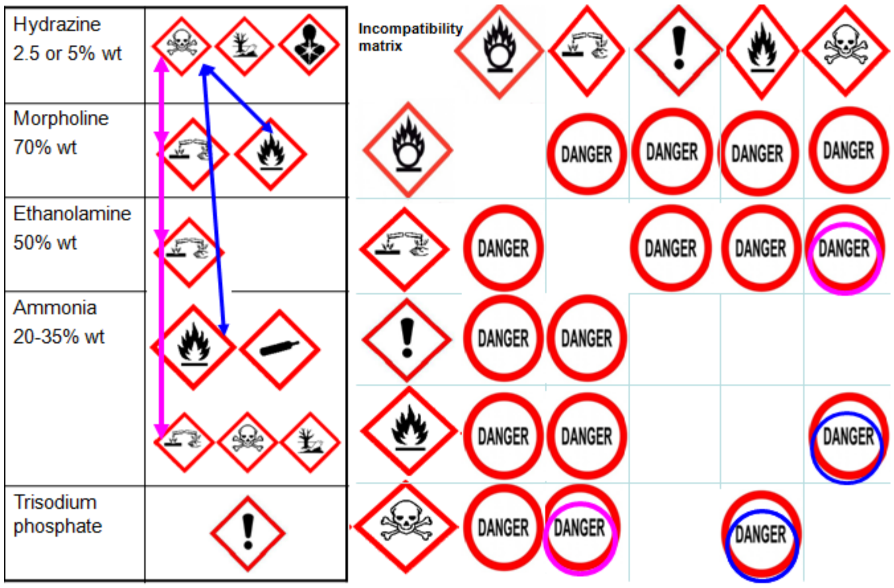


Figure 6: SIR system chemicals incompatibility matrix

Conclusion

Following this HAZOP review, a number of conclusions can be drawn up from the analysis of the UK SIR installation. First of all, HAZOP shown itself to be an exhaustive and sound method of identifying industrial hazards to personnel and equipment, and as such pointed out important actions to minimize or eradicate risks to both staff and plant.

Despite focused on the operating side and the environment, this examination also allowed highlighting important procedural and maintenance considerations to facilitate both everyday use and long term servicing of the system. In addition to that, the participative and imaginative team panel also led to suggestions aiming at improving organizational arrangements and offer better ergonomics of plant, suitable for chemists and operators carrying out unloading and preparation of chemicals several times a week.

In regards with mitigation of risks to operating personnel, HAZOP initiated actions to investigate the hydrazine road tanker and its features such as the unloading pump, the emergency stops and safety valves as well as the UK transport regulations. The secure transfer system connectors were also requested to be, at least, of a different colour for each of the chemicals (since different diameter was claimed not possible by the supplier).

The environmental discharge management was also looked upon and actions taken for the isolation valves to be added on the SEK and SEO effluent exhausts in the hydrazine unloading retention area. For all storage and preparation tanks, a very high level sensor and a flowmeter on the overflow pipes were added so that to allow efficient control and monitoring of discharged effluents and their volumes.

The HAZOP review was also an opportunity to include, as much as possible, any improvements of operability and ergonomics of plant. It was pointed out that the outside pipework should be heat-traced so that to avoid freezing of liquid chemicals and blockages in winter periods. The team panel also identified the need for the Human-Machine Interface to have internal protections, such as to make impossible simultaneous filling and emptying of the tank.

Although being strongly time and resource consuming, HAZOP is also systematic and offer a complete methodology of risk analysis and is particularly suitable for chemical and thermo-hydraulic systems. The actions detailed earlier show clearly that the examination brought to light a number of risks and offered either their suppression or mitigation. For the hazards where the team identified a lack of information, an investigation had been acted to be carried out and actions to be implemented if required. Nonetheless, HAZOP has proven its purpose and value for the installation of this kind and is considered as good practice by both nuclear and environmental regulators.

Acknowledgements

The main author wish to thank M.Alves-Vieira (EDF-DIN-CNEPE), K.Eade (EDF-DIN-CNEPE), K.Lauwereins (EDF-DIN-CNEPE), P.Bonnet (EDF-DPI-DPN-CIVAUX NPP), A.Cooper (NNB-SIZEWELL B), C.Minaret (EDF-DIN-CNEPE), M.Akpobasah (NNB-DA), E.Suant (EDF-DIN-CNEPE).

References

AFNOR, International Electrotechnical Commission, 2001, CEI IEC 61882, International standard, HAZOP and operability studies (HAZOP studies) – application guide,

Royer, M., 2011, Techniques de l'ingénieur - HAZOP : une méthode d'analyse des risques, Présentation et contexte, Royer, M., 2011, Techniques de l'ingénieur - HAZOP : une méthode d'analyse des risques, Principe,

Royer, M., 2011, Techniques de l'ingénieur - HAZOP : une méthode d'analyse des risques, Mise en œuvre,

Royer, M., 2011, Techniques de l'ingénieur - HAZOP : une méthode d'analyse des risques, Sources bibliographiques.