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Power Plant Construction Projects Risk Assessment: A Proposed Method for Temporary Systems of Commissioning

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Abstract: The identification of hazards and risk assessment are key factors in the safety of the industries, including power plants. This paper contains an original risk analysis method that increases the level of safety in commissioning and start-up operations. With the proposed method, which has been tested in real industrial facilities, it has been possible to increase the safety of the system and reduce the likelihood of incidents and accidents in one of the most dangerous stages of project construction activities. This paper also gives an overview of the processes and procedures used in the construction of power plants compared to other industry sectors, proposing some areas for potential improvement. It has been verified that temporary systems used during commissioning apply risk evaluation techniques that do not consider some aspects related to process hazards, something that can be important for the prevention of accidents that historically happen at this stage. Analysis of the data has determined that, in these stages, there have been incidents and accidents, some of them severe. Thus, in this paper, a methodology is proposed. The method allows addressing the particularities of the execution of temporary systems in a safe way by putting into practice an agile and flexible method that can be applied to these particular systems, so that the risk levels can be reduced. The method was applied to one real application representative of this kind of system and yielded excellent results. The proposed methodology is highly recommended as an improvement for the power industry.

Keywords: Structured What-If Technique; hazard identification; risk assessment; power plants; temporary systems

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1. Introduction

Many changes and adaptations have been made in recent years in the electricity sector. The introduction of new technologies has impelled social agents to analyze in more detail some aspects related to the environment and safety of the facilities that were not considered previously. Nowadays, issues related to environmental emissions and industrial safety, and their effects on society, are considered. Although sector self-regulation for standards compliance, with some delay, incorporates new techniques to provide a proper level of safety in facilities, accidents continue to happen, some of them severe. Critically improving methods of hazard identification and risk analysis to increase safety in power plants should motivate researchers and stakeholders towards the implementation of new safety methodologies.

The 2020 statistical report of the International Energy Agency (IEA) [1] includes a study of the trend of world total final consumption (TFC) by source of energy, from the 1970s up to 2018. There has been a sustained increase in the demand for energy, even in the worst years of the last financial crisis. Additionally, the forecast of electricity generation up to 2050 published by the European Union in 2016 [2] shows that conventional power plants will be part of the combination of resources, despite the notable increase in the renewable resources, with a forecast of at least 26% of the total generation in 2050. Therefore, the international market will keep the demand for conventional power plants with fossil fuels in the coming years.

Fossil fuel-fired power plants reach high pressures and temperatures of steam and water for optimal operation. Facilities also use products that can be potentially hazardous and require specific safety measures to reduce potential damage.

Power plant construction projects will keep evolving to incorporate further procedures for hazard identification and risk assessment in order to increase the level of safety and avoid accidents and injuries.

The standard UNE-ISO 31000 [3] establishes the overall guidelines for risk management. It defines risk as the effect of uncertainty on objectives. The standard UNE-ISO 31010 [4] defines the methodology for risk identification considering the company or the project. Reference [5] and the European Directive 2012/18/UE [6], known as Seveso III, also establish the terms hazard and risk.

When evaluating the threat caused by a hazard, the main factors are the likelihood of the hazard and the extension of the consequences. Risk is the term used to define that likelihood of occurrence of a hazard.

A common definition of risk used in the safety industry is:

$$\text{Risk} = \text{Likelihood} \times \text{Magnitude of the consequences}$$

Currently, there are methodologies for risk management that have created an overall framework of risk management that re-evaluate the hazards and risks of an industrial installation in an iterative process [7]. Risk management is an obligation for any company. Organizations have different frameworks for risk management such as methodologies proposed by OSHA [8], by CCPS [9], by API in API 1173 [10], or the American Chemistry Council's (ACC) Responsible Care [11], which establishes 18 basic elements to manage risk in a complete manner.

For any utility that bases its productive capacity on physical and chemical processes, it can be assumed that an improvement in safety will cause a direct reduction in severe accidents. Process safety is at the core of reduction of risk. Process safety is closely linked with the methodology for hazard identification, as per reference [12]. It is commonly accepted that hazard identification and risk management are part of the project life cycle.

In this study, we carried out an investigation of the methods and techniques of hazard identification and risk analysis that are performed during the construction of power plants that use non-renewable sources. A detailed review of the literature is provided, and references are grouped and classified into similar blocks. Due to the difficulties in finding a specific methodology from the literature review, an extensive database of conventional power plants construction projects was used. Projects have been developed by international contractors and original equipment manufacturers in recent decades. Studies carried out in each phase of the project life cycle are reviewed in detail. Figure 1 shows a flowchart with the main steps followed in this research.

Risk analysis includes reviews performed during the initial project stage that usually consider what is necessary for the viability of the plant, up to the necessary risk analysis to be implemented during commissioning and looking through the different stages of the project.

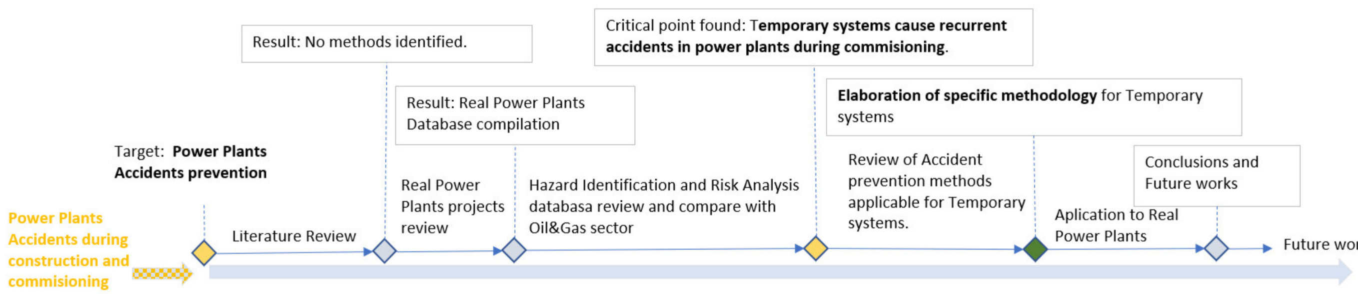

Figure 1. Research steps.

The results obtained from this analysis are compared with the risk analysis that has been carried out systematically in other industrial sectors. Some relevant conclusions are provided that may provide alternative directions for future research.

One of the critical issues identified is that risk analysis for commissioning temporary systems is not usually carried out. A new method for avoiding accidents during the commissioning phase is proposed. The methodology has been implemented in several projects developed in the past 3 years with satisfactory results. Implementation of this methodology is highly recommended for power plant contractors.

2. Literature Review

As part of this study, a systematic review of the scientific literature related to the main subject of the investigation was performed. The aim was to obtain all the relevant information, as well as to know the state of the art of risk assessment and hazard identification methods applied for power plant construction projects. Guidelines of the PRISMA declaration revised in 2020 [13] were followed. Figure 2 shows the PRISMA flowchart of the process followed for this literature review.

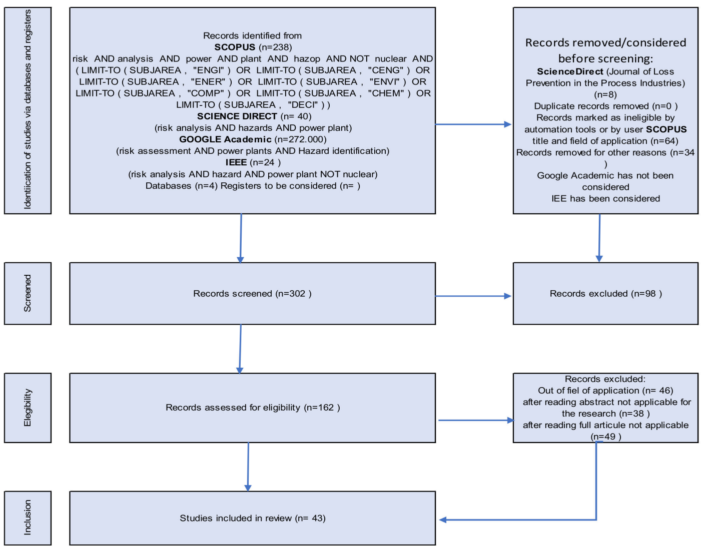

Figure 2. PRISMA flowchart.

The literature shows studies related to the operation and maintenance risks of the plants, including analysis of failures and their impact and associated costs [14–23], papers related to the studies and analysis of the qualitative and quantitative risks of thermal power plants, based on its typology [24–27], hazard identification and risk evaluation tools automation, and literature related to HAZOP of some power plants in operation [28–40], as well as other articles with opinion or information related to accidents that have occurred in power plants, consequence of incorrect operations, leaks, and explosions [41–47]. In general terms, the literature reviewed are present in a dispersed manner, providing relevance to each of the blocks defined. It has not been possible to find a typical and specific methodology for risk analysis and accident prevention for power plant construction projects with clear and focused researching guidelines that can be established by the stakeholders of this industry, as in other industries such as oil and gas.

3. Materials and Methods

Published scientific literature as support for the research are not available. Consequently, it was necessary to look for alternative sources of information that allow establishing risk analysis methods used in the execution of projects by the electricity sector.

We consulted a database of real projects that have been completed, selecting five international contractors that have used different technologies for the execution of the projects. The database included projects of the past thirty years, allowing us to establish a historical vision of the evolution of the analysis methods used over the years.

Figure 3 shows the number of total risk analysis assessments carried out over the years without distinguishing the phase of the project or the type of analysis used.

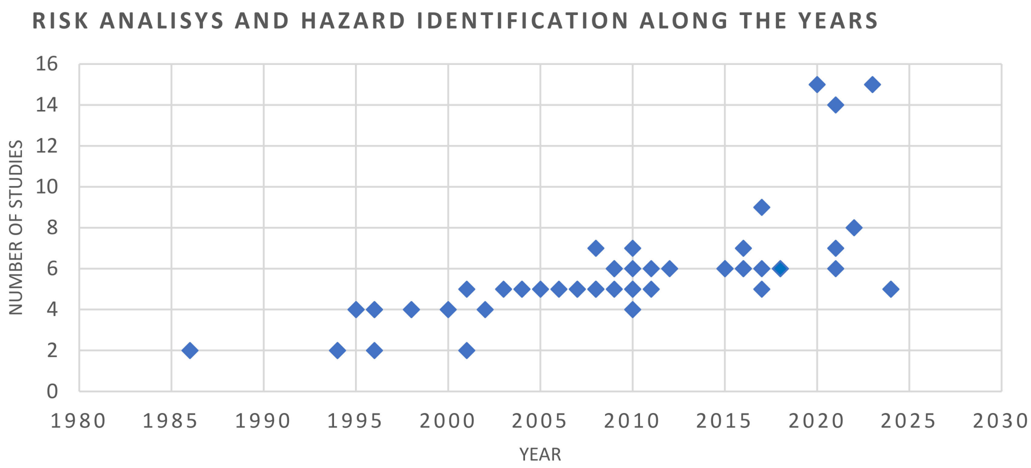

Figure 3. Evolution of risk analysis and hazard identification for power plants over time.

The figure clearly shows how a major disruption occurred in the past 15 years, since the HAZOP technique was widely implemented during project execution. The increasing number of risk analysis and hazard identification assessments in recent years shows how the sector has been implementing prevention techniques and increasing safety in a similar way to industrial sectors.

Table 1 provides an overview of the project database used.

The database is based on 69 projects of conventional power plants, including some refurbishing projects, such as flue gas desulfurization (FGD), and projects for upgrades of the main equipment. The name of the projects and the most relevant data have been redacted due to confidentiality and privacy rights. Details could be provided separately, if necessary, after approval of the companies involved.

For each project, risk analysis and hazard identification methods were analyzed.

The risk analysis and hazard identification methods considered are based on the overall framework defined by the Institute of Chemical Engineers, IChemE, through the Center for Chemical Process Safety (CCPS) [48], and the studies of F. Crawley [49]. It is also important to mention the standard UNE ISO 150008 [50] and standards [51] and [52], which are references for environmental risk management and project management, including risk management. There are other publications that are considered references in this field, including some specific chapters such as analysis with HAZOP [53], and some papers in the field of process safety [54]. Other general references that can also be mentioned include [55–57].

Table 2 provides a primary classification of hazard identification by quantitative, qualitative, and hybrid methods.

Table 1. Project database.

Project N.	Year	N.studies	Early Design					Basic Engineering				Detaill Engineering						Construction		Commisioning & Startup			
			HAZID	FSS/FEA	FHA	QRA	F&G	HAZID Det	FSS/FEA FHA SGIA/SIP	QRA prel HRA	LOPA SIS/SIL	HAZID Det	HAZOP	DB/PR/Flare	RAM	QRA prel HRA	LOPA SIS/SIL	RA/MS JSA	SIMOPS	JSA Check List	SIMOPS Audits	PSSRs	(PSSR)
109	1986	2																1		1			
105	1994	2																1		1			
108	1994	2																1		1			
502	1995	4	1									1						1		1			
505	1995	4	1									1						1		1			
106	1996	2																1		1			
503	1996	4	1									1						1		1			
504	1996	4	1									1						1		1			
104	1998	4	1									1						1		1			
107	1998	4	1									1						1		1			
103	2000	4	1									1						1		1			
110	2001	2																1		1			
609	2001	5	1									1				1		1		1			
501	2002	4	1									1						1		1			
610	2003	5	1									1				1		1		1			
603	2004	5	1									1				1		1		1			
307	2004	5	1									1				1		1		1			
611	2005	5	1									1				1		1		1			
302	2006	5	1									1				1		1		1			
304	2007	5	1									1				1		1		1			
305	2007	5	1									1				1		1		1			
612	2007	5	1									1				1		1		1			
102	2008	7	1							1		1	1			1		1		1			
303	2008	5	1									1				1		1		1			
306	2008	5	1									1				1		1		1			
701	2008	5	1									1				1		1		1			
702	2008	5	1									1				1		1		1			
703	2008	5	1									1				1		1		1			
704	2008	5	1									1				1		1		1			
601	2009	5	1									1				1		1		1			
613	2009	6	1									1	1			1		1		1			
801	2009	6	1									1	1			1		1		1			
101	2010	7	1							1		1	1			1		1		1			
301	2010	4	1									1						1		1			
602	2010	5	1									1				1		1		1			
705	2010	5	1									1				1		1		1			

Table 1. *Cont.*

Project N.	Year	N.studies	Early Design					Basic Engineering				Detaill Engineering						Construction		Commisioning & Startup			
			HAZID	FSS/FEA	FHA	QRA	F&G	HAZID Det	FSS/FEA FHA SGIA/SIP	QRA prel HRA	LOPA SIS/SIL	HAZID Det	HAZOP	DB/PR/Flare	RAM	QRA prel HRA	LOPA SIS/SIL	RA/MS JSA	SIMOPS	JSA Check List	SIMOPS Audits	PSSRs	(PSSR)
802	2010	6	1									1	1			1		1		1			
706	2011	5	1									1				1		1		1			
803	2011	6	1									1	1			1		1		1			
614	2012	6	1									1	1			1		1		1			
606	2015	6	1									1	1			1		1		1			
111	2015	6	1									1	1			1		1		1			
616	2015	6	1									1	1			1		1		1			
607	2016	6	1									1	1			1		1		1			
615	2016	7	1									1	1			1		1		1		1	
617	2016	6	1									1	1			1		1		1			
201	2017	9	1	1						1		1	1			1	1	1		1			
604	2017	5	1									1				1		1		1			
608	2017	6	1									1	1			1		1		1			
605	2018	6	1									1	1			1		1		1			
618	2018	6	1									1	1			1		1		1			
901	2020	15	1		1	1	1	1	1			1	1	1		1	1	1	1	1	1		
112	2021	7	1									1	1			1	1	1		1			
619	2021	6	1									1	1			1		1		1			
113	2021	14	1		1	1	1	1				1	1		1	1	1	1		1		1	1
620	2022	8	1					1				1	1			1	1	1		1			
902	2023	15	1		1	1	1	1	1			1	1	1		1	1	1	1	1	1		
621	2024	5	1		1								1					1		1			
622	2024	5	1		1								1					1		1			

Table 2. Hazard identification and risk analysis methods.

Method [58–61]	**Description**	**Types**	
Qualitative	Methods based on qualitative evaluations; they do not establish a numerical value of the analyzed phenomenon. Qualitative methods can be classified according to scenario-based and non-scenario-based hazard evaluations.	Non-Scenario-Based Hazard Evaluation Procedures	Preliminary Hazard Analysis (PreHA)
			Safety Review
			Relative Ranking
			Checklist
		Scenario-Based Hazard Evaluation Procedures	What-If Analysis [62–64]
			Structured What-If Technique (SWIFT) [65]
			What-If Analysis/Checklist
			Hazard and Operability (HAZOP) Study [66–68]
			Failure Modes and Effects Analysis (FMEA)
Semi-quantitative/Hybrid	Based on the use of qualitative methodologies together with the use of indices to estimate the probability and consequences.	Index-based (Dow [69] F&EI [70], MOND [71], etc.)	
		SIL/LOPA Studies [14,48,49,72–76]	
Quantitative	Based on systematic development of numerical estimates of the expected frequency and severity of potential incidents associated with a facility based on mathematical techniques.	Failure Modes, Effects, and Criticality Analysis (FMECA)	
		Event Tree Analysis (ETA) and Fault Tree Analysis (FTA)	
		Cause–Consequence Analysis and Bow-Tie Analysis	
		Quantitative Risk Analysis (QRA)	

A similar classification is presented in [77], which provides a compilation of the main papers that were published until 2009.

Power plant construction projects are, in general terms, governed by the same principles and complexity as great industrial projects. The PMI [51] establishes that all the projects, independently of the size and complexity, can be configured within a generic structure of a life cycle that consists of initiation, planning and organization, execution, and closeout. The life cycle is the series of stages that a project passes through from its initiation to closeout. Each stage is a set of activities, interrelated in a logical manner, that finalize with one or more deliverables. In this paper, we consider the main stages of the life cycle of a project as follows: engineering stage, which includes three separate stages (conceptual design, basic engineering, and detailed engineering); procurement stage, which is also limited to the same separate stages, but applied for vendors and equipment suppliers (for this reason, it has been omitted); construction stage; and commissioning and start up.

Table 3 provides a review of the safety studies and risk analysis that are developed in the construction projects of a power plant. The structure and guidelines proposed by CCPS in [78] are followed.

Table 3. Risk analysis commonly applied throughout the life cycle of a construction project of a power plant.

Project Stage		Procedure or Study	Description	References
Early design		Industrial safety studies	Environmental Impact Assessment (EIA)	
			Seveso Studies or "Major Hazards Reports"	[6,79]
			Health Risks Assessment (HRA)	
		Process safety studies	Hazard Identification Study (HAZID)	[80]
			Preliminary Quantitative Risk Analysis (prelimQRA)	[81]
Engineering *	Basic Engineering	HSE Plan for Engineering	Hazardous Areas Classification, Safety Data Sheets (SDS), evacuation and escape routes, etc.	
		Detailed HAZID	Hazards included: external and environmental hazards and conditions; process hazards, commonly including from the storage of hazardous materials, pressures and temperatures of vents and leaks; hazards related to occupational health and safety, and hazards related to the project implementation.	
	Detailed Engineering	HAZOP [75]	Two types of HAZOP: HAZOP and HAZOP/SIL. The HAZOP methodology that is applied to power plants is similar to HAZOP performed in other industrial sectors. It is common to schedule the sessions based on division of the power plant into the BOP water and steam systems, boiler and auxiliary systems, gas turbines and HRSGs for the combined cycles, steam turbines, auxiliary systems, and package units.	Examples of HAZOP can be found in [24,27,28,82]
		EHAZOP	HAZOP applied to the design of the electrical systems.	
		Consequence Analysis Studies	It is common to use the techniques of ETA and FTA [77,78]. The calculation tools used to calculate the effects are normally based on the use of commercial software (such as DNV [79], PHAST [80], SCRI [81]).	ETA [83] and FTA [84] DNV [85], PHAST [86], SCRI [87]
		Quantitative Risk Assessment (QRA)	QRA studies provide the hazards, frequency of occurrence, and consequences of the scenarios that are credible in terms of leakages, fire, explosion, toxic clouds, and other accidents that can be severe, not only for the plant itself, but also for the surrounding area.	
		Building Risk Assessment (BRA)	Studies hazards and potential harm to people located in buildings on process sites. In power plants, this method is commonly included as part of the QRA study or the Consequence Analysis.	
		Hazardous Areas Classification	The hazardous area classification consists of two basic documents: the hazardous area classification and the drawings of classified areas. There are two main systems for the classification: NFPA/NEC, NFPA 70 National Electric Code, NEC [82], used mainly in the USA, and ATEX/IEC (IEC 60079) [83].	NEC [88] ATEX/IEC (IEC 60079) [89]
		Other studies	SAFOP (Electrical Systems Safe Operability Review), SAFAN (Safety Analysis), SYSOP (System Security and Operability Analysis), and OPTAN (Operator Task Analysis).	
Construction **		Construction HSE Plan	Requirements related to the risk evaluation for the construction and the safety and health applicable to the project are defined in a Construction HSE Plan. Qualitative methods are used.	Risk Matrix [90] Simplified qualitative method [91]
		Job Safety Analysis (JSA)	The method divides the scope of work in stages, which are also divided into tasks and activities, in a manner so that those tasks and activities will be evaluated separately.	[92]
		Risk Analysis/Method Statement (RAMS)	How, when, and why the control measures identified in the risk evaluation of the JSA are to be implemented.	
		Other studies	HAZCON. HAZCON consists of two stages, the first one being more general, where the construction team identifies with checklists the biggest risks of the project, and the second stage in which a detailed evaluation of the construction risks is provided.	[93,94]
Commissioning and Start-up		ToP (Turn Over Packages)	The power plant is divided into systems that have a defined function for the plant and can be test isolated from the rest. Mechanical, electrical, and I & C systems are included in ToPs, as needed. Walk-down is included in the process to transfer ToP from the construction to commissioning organization usually to the final client of the plant.	
		Test and start-up procedures	These procedures provide necessary requirements to develop the different activities that are necessary for the performance of the different activities and tests of the equipment, components, and systems at the installation.	
		Functional and performance test	Mechanical and electrical functional tests are commonly used in power plants. ASME defines the performance test as "the highest level of accuracy based on current engineering knowledge, taking into account test costs and the value of information obtained from testing for manufactures and end users.	[95], ASME PTC [96]
		Other studies	Other techniques that allow evaluating the hazards just before the execution of the tasks are PSSR (Pre-Start up Safety Review) and Last-Minute Risk Assessment (LMRA). PSSR and LMRA have been applied in power plants very occasionally.	PSSR [97,98] (LMRA) [99]

* HSE Plan defines the studies to be included in a project. It is common in power plants projects to make a distinction between the HSE Plan for engineering and procurement and the HSE Plan for construction. ** Safety in construction is in permanent evolution; guidelines of OSHA18001 [100], or the recent issue of ISO45001 [101] can be considered.

4. Results and Discussion

Currently, the construction projects of power plants include as part of the management system a risk-based process system (RBPS) along the different phases of the project life cycle. However, paying attention to the studies and analyses that are being implemented in other industries, the result, although satisfactory, shows a reactive response of the sector to the inclusion of new methodologies for analysis that are used in other sectors, such as petrochemical, oil and gas, which are leaders in this field due to their media and social impact.

Table 4 shows a summary of the results obtained, making a comparative risk analysis between the oil and gas and power plant sectors.

Table 4. Comparative risk analysis. From Appendix A of [78,102].

Safety Studies Category	Industry	Project Life Cycle Stage					
		Viability Stage		Engineering Stage		Construction	Commissioning and Startup
		Fron End Loading/Initial Studies		Basic Engineering	Detailed Engineering		
		FEL-1 (Appraise)	FEL-2 (Select)	FEL-3(Define)/FEED			
Project HSE Plan Risk Register Action Tracking List	Across all Industries in the comparative study	Updated continuosly throughout project life cycle					
Hazard Identification	Power Plants	Conceptual HAZID		Detailed HAZID	HAZOP	RA/MS JSA	JSA Check list
	Oil&Gas/Petrochemical *	Preliminary HAZID	HAZID	Prelim HAZOP/What If/CheckList	HAZOP Final/What If/CheckList Safety Studies Review	JSA ORR*	Change mangmt temporally piping JSA ORR*
Consequence Assessments	Power Plants	QRA prelim			CCA		
	Oil&Gas/Petrochemical *		FSS/FEA prelim FHA prelim	FSS/FEA FHA SGIA/SIP	FSS/FEA ** FHA ** SGIA/SIP **		
Safety Assessments	Power Plants			DHM prelim HAC prelim EER	DHM HAC RAM (occasionally) EER	Audits and Inspections	SIMOPS (occasionally)
	Oil&Gas/Petrochemical *	Preliminary ISD	rev ISD prelim DHM prelim DB/PR/Flare prelim SVA prelim	**ISD** DHM **HFA** DB/PR/Flare RAM HAC prelim SCE EER SVA SIMOPS prelim Design Case for Safety prelim	**ISD** ** DHM ** **HFA** ** DB/PR/Flare ** RAM ** HAC ** SCE ** EER ** SVA ** **SIMOPS** Design Case for Safety	SIMOPS ** Audits and Inspections Operations Case for Safety	SIMOPS ** Audits
Risk Assessments	Power Plants	QRA preliminar			QRA	HRA	
	Oil&Gas/Petrochemical *	CRA	CRA reviewed	QRA prelim HRA	QRA	HRA	
Risk Mitigation	Power Plants				HAZOP/SIL (LOPA)	Emergency Response Plan	
	Oil&Gas/Petrochemical *		F&G prelim ESD prelim Fire Protection prelim Emerg Response prelim	LOPA SIS/SIL **F&G** **ESD** Fire Protection Emerg Response	LOPA ** **SIS/SIL** ** **F&G** ** **ESD** ** Fire Protection ** Emerg Respons **	Emergency Response **	
Stage Gate Reviews	Power Plants				Design Review	Construction Review	PSSRs (occasionally)
	Oil&Gas/Petrochemical *	Concept Review	Selection Review	Technical Definition Review	Desing Review	Construction Review	PreStartup Safety Review (PSSR)

* Adapted from CCPS GUIDELINES FOR INTEGRATING PROCESS SAFETY INTO ENGINEERING PROJECTS; ** To review as required in accordance with project progress; Legenda: CRA: Concept Risk Analysis; F&G: Fire and Gas; QRA: Quantitaive Risk Analysis; CCA:Cause-Consequence Analysis; HAC: Hazardaus Area Clasification; RAM: Reliability, Availability and Maintainability study; DHM: Design Hazard Management; HAZID: HAZards Identification study; RA/MS (RAMS): Risk Analysis/Method Statement; EER: Evacuation, Escape and Rescue study; HAZOP: HAZard and Operability study; SGIA: Smoke and Gas Ingress Analysis; ESD: Emergency Shut Down; HFA: Human Factors Analysis; SCE: Safety Critical Equipment/Element; FEL: Front End Loading; HRA: Hazards and Risk Analysis; SIP: Shelter In Place; FSS: Facility Siting Study; ISD: Inherently Safer Design; SVA: Security Vulneravility Analysis; FHA: Fire Hazard Analysis; JSA: Job Safety Analysis; ORR: Operational Readiness Review.

The main findings of this paper are the following proposed improvements, which are representative of the current status of process safety in the sector.

- A reactive response of the utility sector to the adoption and adequation of the systems and standards commonly used in other industries of reference in this field was detected. The sector incorporates the improvements and updates that are led by other industrial sectors in this field, slowly and not always adequately. An example is the HAZOP technique incorporated some years late.

- Incorporation of inherently safer design practices at the early stages of the project is an improvement area to be considered. Although the design of the areas of the plant considers the selection of inherently safer designs, it is not implemented as a prioritized and mandatory design, so there are no justifications or specific studies to this objective. A specific study that deals with these relevant subjects for the process safety could be incorporated.
- It would be convenient to implement Human Factor Analysis (HFA) to review the risks and problems related to human factors in relation to ergonomic, potential human errors, and problems such as alarm prioritization, tagging, signaling, noise, and lighting. The incorporation, as a standard practice, of the preparation of specific studies, SIS/SIL and ESD, is highly recommended. This would simplify and clarify the application and compliance with the IEC standards.
- Critical issue. It has been confirmed that construction companies do not perform process risk analysis and HAZOP for the temporary systems usually installed during commissioning and start-up. This can result in accidents during commissioning.

It was also confirmed that the temporary systems, located on the border of the systems that are implemented in the last stage of construction and in the first stages of the commissioning of the plant (pre-commissioning and commissioning), are dealt with with similar considerations to the ones used for the tasks and activities of the construction stage. Obviously, the use of method statements or job safety analysis allows for a treatment not less safe than the one used for other construction activities; however, not all the hazards can be correctly identified if analyses similar to the ones used for other process hazards are not implemented. The different conditions of pressure, flow, and temperature that these systems manage should give them a consideration similar to the one given to the rest of the process systems of the plant.

Additionally, the normal practice of external subcontracting for the mentioned temporary systems, which is recurrent for international contractors, favors the lack of dedication of the safety specialists involved in the process risk analysis that forms part of the rest of the studies of the project.

This paper provides a short description of the temporary systems and proposes an alternative method to the HAZOP study for this type of system, which is quicker and more flexible and can anticipate the real status of the installation immediately before its execution, something that will improve the safety of the operations.

4.1. Temporary Systems for Commissioning

A temporary system is one that develops a defined function during a concrete stage in the construction or commissioning phases. During the finalization of certain construction activities, it is required to use some equipment, components, or supporting systems that allow the performance of the activities by means of the use of temporary elements that, once they have been utilized, are dismantled from the permanent installations. The concept of "non-permanent material" used in the configuration of the system can help to define the scope and limits of the systems herein defined. It is not our purpose to address typical temporary systems used during construction such as props, shoring systems, or sheet piling.

The definition of a temporary system varies depending on the typology of the plant and the services that can be provided by the owner or any of the project stakeholders, but in general terms, temporary systems are usually utilized at the first stages of commissioning, at the time of the finalization of the construction, and during the erection of the equipment and interconnecting piping.

Therefore, the systems identified in this non-exhaustive list can be considered as temporary systems:

1. Process and mechanical systems:
    - Chemical cleaning.;
    - Cleaning with air, water, or other products.

- Steam blowing of piping.
- Piping and temporary installations of liquid or gaseous fuels.
- Inertization of piping and equipment.

2. Electrical systems:
    - Temporary power supply with diesel generators.
    - Temporary interconnections.
    - Provisional power supply and distribution.
    - Uninterrupted and backup temporary power supply.
    - Electrical systems in operation without the final protection settings, and therefore with temporary settings that can produce hazards and risks that are not present under normal operating conditions.
3. Instrumentation and control systems:
    - Protection systems with preliminary settings, since the plant is not operating under normal conditions.
    - Temporary control logics necessary for performance of certain tests.
    - Non-operative alarms or alarms with preliminary settings, because the construction is not completely finalized.
    - Disconnected signals or incomplete control loops, which require modifications in the control logics until the erection is finalized.

For the identification of those systems, among the ones that form a plant that are to be considered as temporary systems, it is highly recommended that they are studied case by case by the plant safety committee, one formed to coordinate and supervise the risk assessment of the commissioning activities of the plant.

Recently, P. Sakar [103] published a detailed paper on the preoperational activities that are required during the commissioning stage of a power plant; some of these can be identified above as part of the temporary systems, commonly accepted by researchers and professionals in the sector.

4.2. Selection of the Methodology

Techniques included in Table 3 of Section 3 are used.

First, it is necessary to assure that information and documentation available to carry out the risk assessment are sufficient and in adequate condition to allow knowing, with necessary detail, the particularities of the process to be analyzed.

Second, the state of the plant for the execution of the tasks should be taken into account. Necessary resources, tools, and devices also are available to carry out the operations.

Two steps can be considered in the methodology to be followed:

1. Initial stage for evaluation of the documentation and state of the installation;
2. Hazard identification and risk analysis on the process and activities considered on the temporary facilities to be evaluated.

Qualitative, semi-quantitative, and quantitative methods were distinguished. Only qualitative methods are considered since the hybrid and quantitative methods exceed the objectives for the evaluation to be carried out on temporary installations.

Within qualitative methods, two large groups of analysis methods were identified:

- Scenario-based;
- Non-scenario-based.

Within the "non-scenario-based" hazard identifications, the following were considered:

- Preliminary Hazard Analysis (PHA);
- Safety Review (SR);
- Relative Ranking (RR);
- Checklist.

Scenario-based methods are as follows:

- What-If Analysis.
- What-If Analysis/Checklist.
- Hazard and Operability Studies (HAZOP);
- Failure Modes and Effects Analysis (FMEA);
- Fault Tree Analysis (FTA);
- Event Tree Analysis (ETA);
- Cause–Consequence Analysis (CCA) and bow tie analysis.

Therefore, for the proper selection of the method to be used, first it is necessary to know if the analysis will be carried out on scenario-based or non-scenario-based hazards.

For the first step of the evaluation, non-scenario-based is selected.

PHA is not applicable for step 1. SR and RR could be selected, but these methods can be used better in step 2. Checklist is the methodology selected for step 1.

In the application of Checklists for step 1, a report is prepared including a list of deficiencies found, together with the resolution proposed. The report must include additionally relevant issues noted by specialists detected in this first review.

Step 2 is the core of the risk evaluation. At this stage, the design of the process is reviewed to verify that the hazard identification and mitigation measures have been considered for the scenarios identified. It is necessary to include procedures, tests, and operating procedures in order to clearly define operations to be carried out on site.

FMEA can be excluded, since this method considers the individual failure modes of an element or a group of elements of the plant. The same is applicable for FMEAC.

HAZOP and What-If Analysis, or adaptations of these techniques, are the most suitable solution for step 2.

The most widespread method for scenario-based process hazard identification and risk assessment is HAZOP. However, in the application of this methodology to temporary systems and, specifically, when the execution of the systems is carried out by subcontracting, it is possible that the project schedule does not allow it due to time constraints.

What-If is a methodology based on the "brainstorming" technique where a team of specialists ask themselves questions about the process and risk scenarios. What-If is less structured than HAZOP, more flexible, and faster, with similar results.

A variation of the What-If method called SWIFT (Structured What-If Technique) [65] has recently been developed for use in healthcare sector, using the What-If technique incorporating previously assigned guide words, which simplifies and limits the work of the specialist team.

Therefore, the proposed methodology is based on the combination of the following techniques, properly applied:

- Checklists.
- Application of SWIFT (Structured What-If Technique) with preselected guide words.
- Application of techniques of HAZOP applied to procedures, using questions related to incorrect operations or non-executed operations.

The proposed methodology herein could be defined as a combination of the What-If and Checklist techniques, denoted as SWIFT/Checklists, with adequate preselected guide words to apply to the target systems.

4.3. Description of the Methodology

The methodology is divided in seven stages. Figure 4 shows the process diagram to complete the risk assessment on the evaluated process.

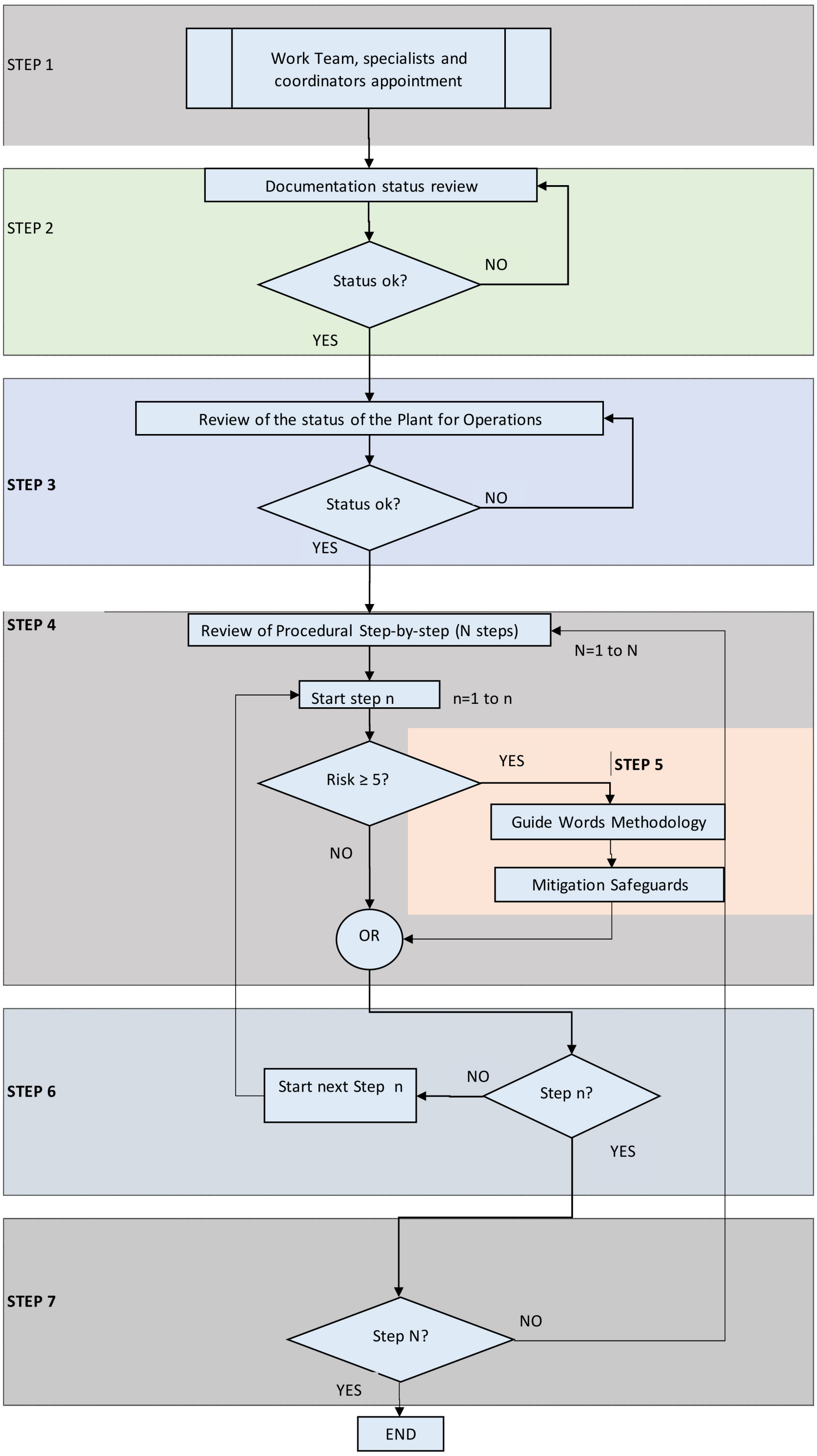

Figure 4. Risk assessment methodology for temporary systems.

The first step (**Step 1**) consists of the formation of the working team. The company that acts as the main contractor establishes the best way to form the team, either by subcontracting an external company specialized in risk analysis or creating the team with specialists from within the company. In any case, a team leader (facilitator) for the review team is assigned. It is recommended to select a person with experience in this type of multidisciplinary studies that base their methodology on brainstorming. Additionally, it is highly recommended to designate a member of the team as secretary or scribe, who will be in charge of preparing the minutes and recording the results of the review. Since the methodology is similar to the one used in HAZOP, or more specifically in What-If, having a well-structured framework of the analysis is fundamental, and specifically, recording the results of the analyzed scenarios is essential to be able to complete the analysis in a satisfactory manner, in case it is necessary review any of the scenarios or the existing or additional mitigation measures.

The leader coordinates the meetings and provides documentation applicable to the risk assessment in order to allow each member of the team to study and review the system, subject to analysis in an individual manner prior to the meeting of the complete team. This is considered **Step 2** of the proposed procedure, also common in this type of studies.

If the result of the analysis is correct, that is, if the documentation that is going to be used by the review team is fit to generate the detailed questions and develop the accident scenarios, a common review will take place, being Step 3.

Step 3 reviews in detail the status of the plant to verify that the operations defined in the procedure and in the associated documentation can be performed. It is important to mention that usually, as part of the documentation, a RAMS (Risk Analysis and Method Statement) is available, which includes, among other documents, a risk evaluation that can be used as a complementary reference to the analysis to be performed on the process.

Once the previous steps have been completed, the team performs in a detailed manner a review and analysis of the risks of each one of the steps and tasks of the activities, providing scenarios for the analysis and evaluation of the risks using the brainstorming technique (**Step 4**). For the evaluation, a risk matrix is used, and it is very convenient to use the same one that the owner has considered adequate for other analysis and risk assessments (QRA, HAZOP, EAC, or others), adapted and simplified to this process, if necessary.

If the result of the risk evaluation in Step 4 is lower than a predetermined value defined by the review team—for instance, a value of 5, indicated in the flow diagram of Figure 4, representing an acceptable level of risk—the team continues with the next step of the procedure and in an iterative way, continue with the next ones until the finalization of the full procedure.

If the risk found is equal or higher than 5 (following the previous example), the team evaluates in detail the hazardous scenario (**Step 5**) identified in this step. The detailed evaluation employs a group of preselected guide words that are described in the following paragraphs. The guide words suggested here can be adapted or extended by the review team, if they deem it necessary. We sought to have sufficient scenarios and guide words that favor the analysis in such a way that can be conveniently structured but allowing, at the same time, some flexibility.

In the evaluation, the available mitigation measures for the process are determined, and in case they are not sufficient, other measures are proposed to reduce the risk to an acceptable level.

The process continue with **Steps 6 and 7** up to the finalization of the full system under review.

Using the procedure of execution of the system is not mandatory but using this kind of document facilitates the analysis as it provides a base structure for the review.

It is fundamental to have a system to manage the changes and a verification of the implementation of the actions that are a result of the application of the methodology, to have at all times the real status of the installation.

4.4. Procedure

To establish in a rigorous manner the procedure to follow, the guidelines and steps described by the American Institute of Chemical Engineers in [16] should be followed. Once the scope and battery limits of the temporary system to be evaluated have been defined, the three following blocks should be studied, which have been proposed historically for each one of the analysis methods proposed:

1. Preparing for the review, including the scope of the review and the necessary documentation.

2. Performing the review, establishing the basic rules for the review, and the preselected guide words.
3. Documenting the results of the review adequately.

4.4.1. Preparing for the Review and Necessary Documentation

For the application of the proposed methodology, the first step is to consider the scope of the review that will be performed by the review team. In practical terms, in temporary systems, the scope can be established in an approximate manner, taking into account the temporary character of the activities and operations that will take place, something that precisely determines the battery limits of the system under study.

The person in charge of establishing the scope of the review and procuring the documentation that is necessary for the team to perform its duties is the team leader. The team leader, in agreement with the specialists who were part of the design of the temporary system, and jointly with the representatives of the safety committee, establishes the scope of the review, the number of sessions, and the documentation necessary to achieve the sought effectiveness. There should be as many meetings as necessary to properly establish the scope.

Establishing a safety committee at the beginning of commissioning is a highly recommended practice in terms of safety and risk prevention for a stage characterized by the hazardousness of its activities. The members of the safety committee are established by the senior management of the company together with the project management and the commissioning management, but in general terms, it is recommended that the committee is formed by a person in charge of HSE who will lead the committee, a person from the construction team, another from commissioning, and finally, a person in charge of engineering. All of them should have wide experience and autonomy to make decisions and give recommendations.

It is common that the team leader, with the secretary, meets the specialists designated by the project management and the safety committee to review the details of the scope and the special features of each temporary system, before involving the specialist in the safety review. The number of meetings and necessary clarifications are defined by experience, as long as the company that executes the project starts and learns the process.

In order to perform the risk evaluation, it is common that the following documentation is made available to the review team:

1. Detailed scope of the system, including lists with battery limits and system tie-ins.
2. Description of the process, base of the temporary system to be implemented.
3. Flow diagrams and P & IDs of the system.
4. Lists and data sheets of the chemical products that will be used in the process of the temporary system. Safety data sheets of the products (SDS). Preferably, the SDS of the products will be provided in the official format of the country where the project takes place, or in the format of international organizations, always in accordance with the normal practices of the product supplier.
5. Lists and data sheets of the equipment comprising the systems.
6. Layout drawings of the equipment and general arrangement where the location and layout of the equipment and components of the temporary system are shown.
7. Isometric drawings and/or piping plan drawings of the system. It is important that this documentation show the scope of the temporary system and the interconnection with the permanent installation.
8. List of the material parts of the temporary system: data sheets of piping and/or components in case these include any not forecasted for the project. It is recommended to list the requirements of the equipment comprising part of the permanent installation when required. This facilitates the identification of mistakes in the design conditions of the equipment, components, and others and facilitates the review.
9. Procedure for the execution of the system. The following points, as a minimum, shall be included:

a. Procedure for filling the system. Considering the initial conditions of the system.
b. Procedure for the start-up and initial start-up.
c. Procedure for normal and emergency operation.
d. Procedure for shutdown.
e. Other procedures as necessary.

The procedures shall be complete and structured to clearly establish the requirements and necessary conditions to execute the step, indicating clearly also the conditions to establish the step as achieved and proceed with the execution of the next one. Sometimes, the procedures are prepared in a generic manner and do not establish the conditions for a step and for an achieved step; something that can facilitate the increase in the risk of the system.

10. Risk evaluation of the system. In this point, the usual activities related to the installation and handling of chemical products, as well as the main hazards and risks associated with the operation, are included. Normally, this is approached from a perspective related to the occupational health of the workers, and not so much from the point of view of identification of hazards and risk evaluation of the process.
11. Procedures for sampling in case they are required by the system (for example, to determine certain parameters of water or steam in systems that provide a certain degree of cleanliness).
12. Inspection and test plan. It is possible that this plan, besides incorporating the inspections of the activities of the system, incorporates inspections during the manufacturing of pieces or components necessary for the system.
13. Other documentation that is considered relevant to perform the risk assessment with the required guarantees by the specialists. For example, ambient conditions for some tests, notices to the nearby population or to the authorities, etc.

Once the battery limits of the system have been established, and the necessary documentation and the activities to be developed by the review team for the complete analysis of the system or systems have been planned, the process starts with a review of the documentation of the first plant temporary system. The leader and/or the secretary of the review team compiles the documentation and sends it to the review team.

4.4.2. Performing the Review. Rules and Guide Words Recommended

Once the working team has been formed and the documentation and the scope of the review have been established, the specialists proceed with study of the documentation in an individual manner to verify, on one side, that the documentation is in an adequate status to proceed with the risk assessment and, on the other side, that the plant is also up to the required degree of progress as necessary to perform the activities of the temporary system. It is recommended that each specialist performs this analysis individually and independently and then uses the first meeting to compile the conclusions achieved by each member of the team.

The team leader will be in charge of arranging the meeting and will lead it to achieve a conclusion. After this first meeting, the team will be able to conclude:

1. That the status of the system and the documentation are acceptable to proceed with the risk evaluation; or
2. That the status of the system and/or the documentation are not acceptable to allow proceeding with the risk evaluation.

In the first case, the team will proceed with the risk evaluation. In the second, the comments on the documentation will be agreed and sent to the project team to proceed with its correction, with the aim of proceeding with the risk evaluation as soon as possible. It can be easily understood how negative the second situation is for the project, because once the activities have been started, the correction must be performed as soon as possible to minimize the impact on the project schedule.

The team can proceed with the risk evaluation as detailed below.

Previous verifications

Checklists are used to verify that the system is on site in the adequate conditions (see Figure 5).

System	xxxxxxxx	**Hazard evaluation** Project name		Company logo		
Code Number	xxxxxxxx					
SubSystem	N/A	Cod/Equipment Description		Document Attached	Yes ☐	No ☐
Drawing or Procedure: xxxxxxxxxxxxxxx	Unit: xxx	Method: Structured What If /Check List		Doc. Type: xxxxxxxxxxxxxxxxxxxxxxxxxx		

System operation Pre-requisites				
Description	Yes	No	N/A	Remarks
Are the required auxiliary systems and their conditions identified?	☐	☐	☐	
Operatin conditions of the temporary systems are defined?	☐	☐	☐	
Are the HSE requisites identified?	☐	☐	☐	
Personal Protection Equipment (PPEs) are identified?	☐	☐	☐	
Communication means	☐	☐	☐	
Accessibility	☐	☐	☐	
Lighting	☐	☐	☐	
Permits to Work (PTW) approved and issued?	☐	☐	☐	

Figure 5. Checklist format example.

At least, the three following blocks will be verified:

1. Health and safety at work issues. Special attention shall be given to the requirements of HSE and to ensure the provision of personal protection means, that communication devices are available and operative, that accessibility to the working area is adequate, that the permits to work have been issued, that Job Safety Analysis (JSA) has been performed, and that the required control and mitigation measures of the risks have been implemented.
2. Emergency systems, such as fire protection and public address systems are checked.
3. Issues related to the operation of the system are reviewed. Automatic and manual operations, training of the operators, and necessary temporalities required for the operation of the system are also checked. Steps of the sequences are correctly identified and the criteria for achievement of the steps are also identified.

The safety review will be performed for the normal operations of the system such as:

- Initial fill of the system.
- Start-up of the system.
- Shutdown of the system.
- Normal operation.
- Emptying of the system.

Procedure of analysis: Basic rules

The review is based on the technique of brainstorming, with review meetings that will be attended by the specialists designated by the safety committee in accordance with the project management and the engineering departments of the company.

The brainstorming technique is based on scenarios and follows up methodology used for other risk evaluations, such as HAZOP or What-If Analysis.

The review meetings starts with a basic explanation of the process provided by the designated process engineer or the team leader, who gives the main key points to the rest of the team. This presentation should be brief and focused on the aspects related to safety and the operation procedures included in the system. The members of the team already know the special features of the system.

The approach of the review should be focused on the procedure to perform the operations required by the system, initial operations, start up, and shutdown. Scenarios of incidents directly associated with the operation modes are identified and evaluated. The response of the operator to these scenarios are sought. The analysis is focused not only on the design of the system in relation to the identification of the forecasted safeguards to mitigate the consequences of the analyzed hazardous scenarios, but also aspects related to human factors. The temporary character of these systems must be taken into account, ensuring the study is focused on reactions and possible mistakes when evaluating the different scenarios. Additionally, the forecasted safeguards may not be as effective as in other processes, precisely due to the temporary character of these installations.

The analysis should look for vulnerabilities of the system and focus on the analysis of "what if" situations, looking for potential errors of the operator in the execution of certain steps of the sequence, or by not executing the step, or in other circumstances that can be identified by the review team. As it happens with other methodologies of analysis, it is not convenient for the meeting to exceed four to six hours of work per day, and it is not recommended to extend the meetings for a temporary system for more than two or three days of a week.

Meetings should be performed with a pre-established script, incorporating the steps of the procedure that will be evaluated based on defined scenarios. That definition of the scenarios should be obtained by using the preselected guide words.

The team leader evaluates the convenience of splitting the steps of the procedure into other ones if the complexity of the process or the analysis requires it. The team leader also encourages the members of the team to include other scenarios in case the evaluation requires it.

When evaluating a procedure, it should be subdivided into steps. The team evaluates the complete procedure from start to finish. It is not convenient to interrupt or modify the logic of the procedure, unless the considered scenario recommends it.

The team evaluates each procedure step in accordance with the guide words of the resulting scenario from the application of the key questions "what if . . . ", "how could . . . ", or in other cases, if the pressure or the temperature obtained or controlled in the step is higher or lower than expected. The team establishes, in accordance with simple criteria of categorization, the probability of occurrence and the consequences on a scale from one to five, as shown in the tables of Appendix A Tables A2 and A3.

With the values obtained for the likelihood and for the consequences of a risk scenario identified, the product of both magnitudes is obtained and based on the risk matrix (see Figure A1), provides the final estimation of the value of the identified risk in that evaluated scenario.

The risk matrix commonly used is the project risk matrix, which should be simplified in order to allow the review team to quickly and efficiently establish the level of risk identified, with the aim of "filtering" scenarios that are dangerous or that can end up being dangerous.

Once the risk evaluation for the steps of the sequence of the procedure has been performed, the team proceeds to evaluate the details of those scenarios identified as being of medium or high risk, leaving aside those with low risk.

For the detailed risk evaluation of each scenario preliminarily evaluated, the usual format of the What-If technique is followed [16].

The analysis of the evaluation of the hazards, their causes, the consequences, and the safeguards forecasted in the design to mitigate the potential damage should be evaluated in detail for each of the identified scenarios in the analysis and in the preliminary risk evaluation by the review team.

The best time to perform this detailed analysis is subject to the election of the team leader and the team itself; however, it is recommended to perform it immediately after the identification of the level of risk for each scenario evaluated in the preliminary analysis by the review team. It is also possible that the first session is dedicated to a preliminary review, and the second one to the detailed review,

For the correct performance of the analysis, it is recommended to use the general guidelines provided in [16,49,68], among others.

Guide Words

The methodology takes the basis from the risk evaluation based on procedures [16] and uses the Structured What-If Technique (SWIFT), with the purpose of guiding the review team towards the more determining aspects of the procedure and limiting their review time to make it as effective as possible. For this purpose, the evaluation of the following situations or scenarios of incidents were established, due to the omission of a step (errors due to not performing a step) or to the execution of a step (its incorrect performance). The Guide Words are defined in Table 5.

Table 5. Guide words and their meaning (Reprinted with permission from Ref. [48]).

Guide Word	Meaning Guide Word When Applied to a Step
Omission of the step	The step is not done or part of the step is not done. Some possible reasons include the operator forgot to do the step, did not understand the importance of the step, or the procedure did not include this step
More than/Less than	Execution of the step is carried out incorrectly providing more/less amount than required. It can also be understood as an action performed by excess or by default, opening at 35% instead of 20%... in the case of 3 valves A, B and C that must be opened, only 2 open or open more than those indicated...
Before/After	Step is performed before or after what is required in the procedure. For instance, operator must wait one minute and perform the action before the time has elapsed or after...
Step executed in a wrong order	Step is executed in a wrong order, before or after when it is required or a subsequent step is performed at this time instead of the expected step
Action executed wrongly	The step is not performed as intended. Some possible reasons include the operator does too much or too little of the stated task, the operator manipulates the wrong process component, or the operator reverses the order of the steps, wrong operation conditions (pressure, temperature,...)

Figure 6 provides the format for the application of the risk evaluation of the methodology.

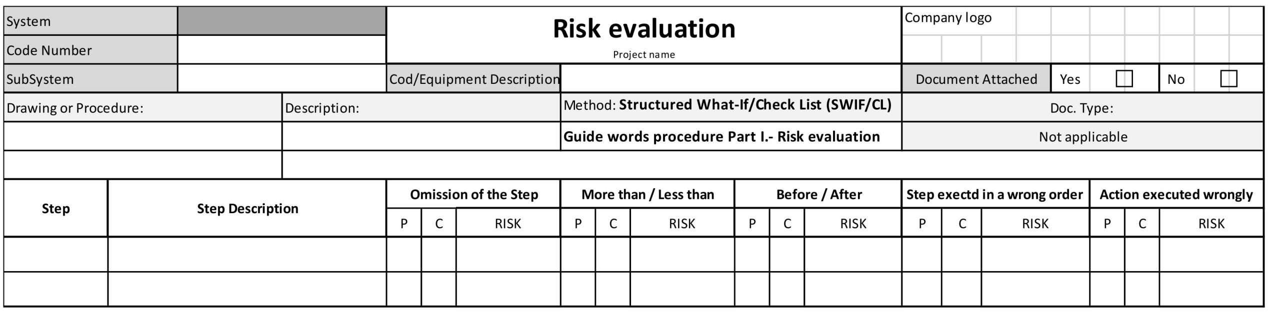

Figure 6. Procedure-based temporary systems risk assessment format.

4.4.3. Documenting the Results

Like in any other study, documentation is essential to ensure that the findings and improvements of the team become measures that are effective for the elimination or reduction of the identified hazards. In the following appendix, an example of the formats and documentation of the results is provided.

Documenting the results, even discussions and ideas that have not been implemented, should be executed in a coherent manner in order to allow other review teams in future projects to use the same scenarios for their own analysis.

4.5. Application of the Methodology to a Real Project: Case Study

The methodological proposal described here was successfully applied in several power plants and in different temporary mechanical systems, including the following:

- Chemical cleaning of boiler and steam and water mechanical systems such as boiler feedwater, condensate, and steam systems.
- Cleaning with air, water, or other products.
- Steam blowing.
- Piping and temporary installations of liquid or gaseous fuels.
- Lube oil flushing.

The proposed method bases its methodology on the success of other similar risk analysis and hazard identification methods that have provided satisfactory results over the years. The method is also based on the formation of specialized work teams that, through workshops and group meetings, implement the brainstorming technique through questions with predefined guide words.

The main results of the application of the method can be summarized as follows:

- Installation of adequate protection devices and equipment that guarantee safety of operations.
- Verification and installation of additional local interlocks, such as thermal and pressure relief valves that increase the safety level of the temporary installation.
- Incorporation of additional alarms and logics in the control systems involved, reducing the risk levels of certain operations.
- Issues related to operational status of the control systems during temporary operations.
- Alternative solutions of system configuration are proposed to avoid dangerous situations, accidents, or failure of equipment and components that could be working out of design conditions.
- Recommendations are made to guarantee the level of education and training of the operators who will be in charge of the operations.
- Preparation of specific checklists is proposed.
- Double verification in the field can help to increase the safety level of operations.
- Other recommendations related to spare parts or industrial safety is proposed.

Appendix A includes a detailed case study for a power plant constructed in 2021. The method has been applied for chemical cleaning of the CFB boiler and auxiliary systems. The procedure for chemical cleaning was applied for the usual steps of the temporary system:

- Filling test and leak test.
- Initial cleaning in closed circuit.
- Chemical cleaning.
- Drainage of the system.
- Final rinsing.

5. Conclusions

This paper describes a risk analysis methodology not used until now in this sector. The method proposed increases the level of safety in commissioning and start-up operations in power plant construction. The proposed method has been tested in real industrial facilities, increasing the safety of the system and reducing the likelihood of accidents in one of the most dangerous stages of project construction activities.

An investigation was carried out on the methods and techniques of hazard identification and risk analysis that are performed during the construction of power plants.

A detailed review of the literature is provided herein, with the references grouped and classified into similar blocks.

Considering the stages of the project life cycle, procedures and studies carried out in each phase are reviewed. The results obtained from this analysis are compared with the risk analyses that have been carried out systematically in other industrial sectors. Some relevant conclusions are presented that may provide alternative directions for future research.

It was verified that in temporary systems employed during the last stages of construction and commissioning, the risk evaluation techniques used do not consider some aspects that are important for the prevention of certain accidents during these activities. Historical records show that many accidents happen at this stage, so delving into the measures and analysis techniques applicable to this type of system can provide high performance in terms of mitigating potentially dangerous situations.

A work methodology is proposed that allows addressing the particularities of the execution of temporary systems in a safe way by putting into practice an agile and flexible method that can be easily applied to these particular systems, so that the risk levels that are usually reached in these configurations can be reduced.

The method combines different techniques traditionally used for process industries and others employed for the health sector not employed before in industrial plants. The combination of these methods comprises the novel methodology presented in this paper. The method has been applied successfully for several power plants and temporary systems. This paper includes the results of one case study, showing that the method constitutes a useful tool for the prevention of accidents during the commissioning of this kind of system, so the proposed methodology is recommended for application in the future.

For steam blowing and chemical cleaning systems, it has been possible to reduce the risk level of temporary installations in combined cycle plants, as well as in fossil fuel plants, by incorporating venting and safety systems, avoiding potential accidents. The risk for cleaning gas and steam turbine lube oil pipes was also reduced.

The main strengths of the proposed method are as follows:

- It is an agile method that allows identifying hazardous conditions and risks during specific processes in temporary systems.
- The method uses and combines techniques with proven results, such as brainstorming.
- The short execution time required allows quick and efficient implementation.

The main weakness of the proposed method are as follows:

- The method is not considered itself by international standards, unlike others such as HAZOP.
- It is necessary to know the real state of the temporary installation before carrying out the risk analysis, which depends on information provided by others.
- The necessary materials must be on site for the execution of the tasks.

With the proposed methodology, future lines of work and applications can be pursued, such as:

- Application to temporary installations in solar thermal renewable energy plants such as thermal salt storage systems, e.g., salt melting processes or salt tank filling processes, as well as specific operations for the safety of these facilities.
- Application with the necessary adaptations to plants that use hydrogen as fuel, either in installations similar to those described here, or those that are currently under development.
- Extend the application of the proposed methodology to other disciplines, such as temporary electrical systems, with the necessary adaptations as well as the selection of the most appropriate guide words and the checklists that are required based on the new proposed systems.

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Appendix A. Study Case: Application of the Methodology to a Real Power Plant

The case study herein was one of the first applications of the proposed method. The power station is a 100% biomass-fueled located in northeast England. The plant is one of the world's largest renewable energy plants, providing 300 MWe (gross) of renewable energy electricity, enough to power around 600,000 homes.

The biomass fuel is transported into the fuel store silos, from where it is conveyed into the boiler daily storage silos for firing. The power plant consists of one circulating fluidized bed (CFB) boiler and one condensing steam turbine generator (STG) with an air-cooled condenser (ACC) and all necessary auxiliary equipment. The CFB boiler has dual fuel and light fuel oil for unit start-up and biomass as the main fuel for full load.

As part of the commissioning activities, chemical cleaning of the CFB boiler and auxiliary systems was carried out.

The chemical cleaning of the installations of a power plant is usually performed by preparing independent cleaning circuits. Depending on the type of plant, there are different circuits and different configurations. The procedure for chemical cleaning is usually composed of the following steps:

- Filling test and leak test.
- Initial cleaning in closed circuit.
- Chemical cleaning.
- Drainage of the system.
- Final rinsing.

Before the start of the steps of the procedure and before the restart of any sequence, an inspection of the status of the system is carried out to guarantee that the temporary connections and the alignment of the equipment is correct, and that the steps of the procedures have been executed in an adequate manner.

The chemical cleaning temporary system mentioned here uses temporary pumps for chemical cleaning to circulate the chemical solutions that are necessary and provide the cleaning factors required for the piping to be in an acceptable status for the operation of the plant. Temporary connections are normally used by means of flexible hoses that connect the equipment and permanent components of the system with the non-permanent or temporary equipment and components.

In the first step of the operations of the system, the operator proceeds with filling of the system and performing a leak test before dosing the chemical reactants.

In order to provide a detailed description of the activities that must be performed for each step of the chemical cleaning method, Table A1 shows a small number of steps analyzed by specialists to evaluate the risks of each of the scenarios considered for the procedure and the temporary installation using guide words of the structured method.

Table A1. Preliminary risk assessment based on guide words.

System / Code Number	Chemical Cleaning / Chapter 7.1	Risk Evaluation Project Name									Company Logo					
SubSystem	N/A	Cod/Equipment Description							Document Attached			Yes ☐			No ☐	
Drawing or Procedure:		Description:			Method: Structured What-If/Check List (SWIF/CL)						Doc. Type:					
7.1.2.1.-Chemical Cleaning		Light F.O. Chemical Cleaning Procedure			Guide Words Procedure Part I.-Risk Evaluation						Not Applicable					
Activity: 7.1.2.1.1.-Initial Filling & Leak Test		Description: Temporary Connections Flanged or Threaded and Elements to Be Removed or Replaced														
Step	**Step Description**	**Omission of the Step**			**More Than/Less Than**			**Before/After**			**Step Exectd in a Wrong Order**			**Action Executed Wrongly**		
		P	**C**	**RISK**	**P**	**C**	**RISK**	**P**	**C**	**RISK**	**P**	**C**	**RISK**	**P**	**C**	**RISK**
1.1	Fuel tank connections preparation															
1.1.1	Remove check valve internals	3	3	9	1	1	1	1	1	1	3	1	3	3	3	9
1.1.2	Remove valve internals	3	3	9	1	1	1	1	1	1	3	1	3	3	3	9
1.1.3	Prepare DN50 PN16flange connection	3	1	3	1	1	1	1	1	1	3	1	3	3	3	9
1.1.4	Prepare DN100 PN16 flange connection	3	1	3	1	1	1	1	1	1	3	1	3	3	3	9
1.1.5	Remove valve internals	3	3	9	1	1	1	1	1	1	3	1	3	3	3	9
1.1.6	Blind PSV	3	3	9	1	1	1	1	1	1	3	1	3	3	3	9
1.1.7	Prepare DN50 PN16flange connection	3	1	3	1	1	1	1	1	1	3	1	3	3	3	9

Taking as an example step 1.1, which consists of the elimination of the internals of the non-return valve to allow the flow of the chemical cleaning fluid and to preserve the internals in adequate conditions for the operations, the following scenarios are evaluated:

What if the elimination of the internals of the non-return valve is omitted?

First, the likelihood of occurrence is analyzed. The team determines that in this case, the likelihood is occasional, that is, not frequent, because this replacement can occur only from time to time. Therefore, it establishes a value of 3 for the likelihood of occurrence according to Table A2.

Table A2. Likelihood evaluation. Adapted from [104].

Value	Description	Reference Values for Estimation
1	Highly unlikely	Extremely remote chance of occurrence (<10^{-5} year)
2	Unlikely	Rare event. An event not likely during operations (1×10^{-4} year)
3	Likely	An infrequent event. An event that may occur during operations (1×10^{-3} year)
4	Probable	An event likely to occur in working lifetime of plant operations (10^{-1} to 10^{-1} per year).
5	Frequent	Happens several times per year. A common event that is likely to occur several times per year.

Next, the consequences of not removing the internals of the non-return valve are evaluated. The evaluation of the consequences is carried out for people and the environment, and the consequences for the equipment are also evaluated considering Table A3.

Table A3. Evaluation of consequences [104].

Value	Description	People	Environment	Assets
1	Negligible	Slight: First aid injury	Loss of containment: No escape to the environment.	Minor equipment damage: No delay in operations.
2	Minor	Minor injury: No irreversible effect	Loss of containment: Minor escape to the environment.	Minor equipment damage: Up to 1 day delay in operations.
3	Significant	Major injury: Permanent disability and health effects	Loss of containment: Significant escape to the environment.	Minor equipment damage: Several days of delay in operations.
4	Severe	Fatality/ies (1–2): Multiple major injuries/permanent disability	Major damage: Loss of containment with significant escape to the environment.	Major impact: Severe damage to assets. Extended loss of operations. Partial loss of plant unit.
5	Catastrophic	Multiple fatalities on-site and/or several major injuries off-site	Extensive damage: Major loss of containment.	Massive impact: Total loss of major plant unit and possible damage to adjacent units.

In this case, it is determined that for the people, there is no relevant risk, nor for the environment; however, for the equipment, there will be minor damage, but the impact of the replacement of some potentially damaged internals can have as a consequence the delay of several days or weeks in the operation of the system, in case there are no specific spares for the internals. Therefore, it is determined that the consequences are established with a value of 3 according to Table A3.

Once the likelihood and the consequences are quantified, the risk is obtained as the product of the two values; for the scenario under study, the value of the risk is 9, which in the risk matrix of Figure A1, is established as a medium risk (yellow color).

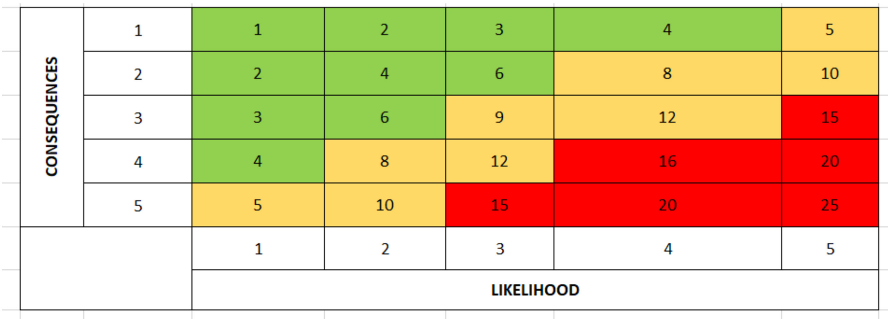

Figure A1. Risk matrix [104].

The team continues studying scenarios resulting from other pre-selected questions, such as what if the execution of the step is taken in an incorrect manner with more or less fluid? What if this step is performed before or after indicated? What if the step is executed in an incorrect order? Finally, the scenario considering what if this step is executed in an incorrect manner is studied; for example, some strange elements are maintained partially or inside. In this case, the result of the evaluation, depending on how incorrect that execution could be, may influence the schedule of the project in case the valve is significantly damaged, something that may lead to a medium risk scenario.

When the risk obtained in the evaluation is yellow (medium risk) or red (high risk), the team proceeds with a detailed evaluation of the risk scenario, to determine, in greater detail, the consequences and the mitigation measures existing for each identified scenario. The team provides recommendations when the available measures are not sufficient or are not considered adequate for the identified risk.

Therefore, as an example, for the cases analyzed before, the result is as indicated in Table A4.

Table A4. Risk assessment for medium- and high-risk scenarios.

System	**Chemical Cleaning**	**Hazard Evaluation Project Name**		**Company Logo**			
Code Number	**Chapter 7.1**						
SubSystem	**N/A**	**Cod/Equipment Description**		**Document Attached**	**Yes**	☐	**No** ☐
Drawing or Procedure:		**Unit:**	**Method: Structured What-If/Check List**	**Doc. Type:**			
7.1.2.1.- Chemical Cleaning		**Light F.O. Chemical Cleaning Procedure**	**Guide Words Procedure Part II**	**Not Applicable**			
Node: 7.1.2.1.1.- Initial Filling & Leak Test		**Description: Temporary Connections Flanged or Threaded and Elements to Be Removed or Replaced**					
Item	**Deviation**	**Causes**	**Consequences**	**Safeguards**	**Recommendation**		
1.1.1	Remove check valve internals Case: Omission of Step Case: Action executed wrongly	Operator mistake	1.- Damage to valve trim 2.- Neccesary spare parts trim valve 3.- Commissioning schedule delay	1.- Test and Inspection Plan Check List Paragh 4.2. Walkdown to check step completion	1.- Be sure spare parts availability 2.- To Include a Task List with a specific checklist for checking that the step has been properly carried out. 3.- to define an independent field team for review correct execution of the step. On field double checking. 4.- To Incorporate a signature of the team (operator and supervisor) responsible.		
1.1.2	Remove Control valve internals Case: Omission of Step Case: Action executed wrongly	Operator mistake	1.- Damage to valve trim 2.- Neccesary spare parts trim valve 3.- Commissioning schedule delay	1.- Test and Inspection Plan Check List Paragh 4.2. Walkdown to check step completion	1.- Be sure spare parts availability 2.- To Include a Task List with a specific checklist for checking that the step has been properly carried out. 3.- to define an independent field team for review correct execution of the step. On field double checking. 4.- To Incorporate a signature of the team (operator and supervisor) responsible.		

Hereafter, some examples of the table of the preliminary risk assessment of the most relevant risks of the system (Table A5) are provided, as well as the evaluations of the risks that are more important for the application of the methodology, and that give as a result the implementation of some mitigation measures that can be interesting for its implementation in the operations, in the inclusion of new components in the system and the inclusion in the temporary system (Table A6).

Table A5. Preliminary risk assessment for degreasing, acid, and passivation stage operations.

System	**Chemical Cleaning**	**Risk Evaluation Project Name**								**Company Logo**						
Code Number	**Chapter 7.1**															
SubSystem	**N/A**	**Cod/Equipment Description**								**Document Attached**			**Yes** ☐		**No** ☐	
Drawing or Procedure:	**Description:**				**Method: Structured What-If/Check List (SWIF/CL)**					**Doc. Type:**						
7.1.2.1.- Chemical Cleaning	**Light FO Chemical Cleaning Procedure**				**Guide Words Procedure Part I.- Risk Evaluation**					**Not Applicable**						
Activity: 7.1.2.1.3.- Chemical cleaning	**Description: Fuel Oil Chemical cleaning**															
Step	**Step Description**	**Omission of the Step**			**More Than/Less Than**			**Before/After**		**Step Exectd in a Wrong Order**				**Action Executed Wrongly**		
		P	**C**	**RISK**	**P**	**C**	**RISK**	**P**	**C**	**RISK**	**P**	**C**	**RISK**	**P**	**C**	**RISK**
3.1	Heat up system to approximately 45 °C															
3.1.1	Check Auxiliary boiler is ready for Operation	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3.1.2	Verify all connections are correctly installed.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3.1.3	Start up Auxiliary Boiler.	1	1	1	3	4	12	1	1	1	1	1	1	3	3	9
3.1.4	Increase load as needed	3	2	6	3	4	12	1	1	1	1	1	1	3	3	9
3.1.5	Open manual valve for heating header of chemical cleaning solution	1	1	1	3	4	12	1	1	1	1	1	1	3	3	9

Table A5. *Cont.*

System Code Number	Chemical Cleaning Chapter 7.1		Risk Evaluation Project Name		Company Logo		
SubSystem	N/A	Cod/Equipment Description		Document Attached	Yes ☐	No ☐	
Drawing or Procedure:	Description:		Method: Structured What-If/Check List (SWIF/CL)		Doc. Type:		
7.1.2.1.- Chemical Cleaning	Light FO Chemical Cleaning Procedure		Guide Words Procedure Part I.- Risk Evaluation		Not Applicable		
Activity: 7.1.2.1.3.- Chemical cleaning	Description: Fuel Oil Chemical cleaning						

Step	Step Description	Omission of the Step			More Than/Less Than			Before/After			Step Exectd in a Wrong Order			Action Executed Wrongly		
		P	C	RISK	P	C	RISK	P	C	RISK	P	C	RISK	P	C	RISK
3.1.6	Control Temperature up to 45 °C of water throug local temperatura indicator	1	1	1	3	3	9	3	3	9	1	1	1	1	1	1
3.2	Degreasing stage															
3.2.1	surfactant 0.05% and caustic soda 0.25%	1	1	1	4	4	16	1	1	1	3	3	9	1	1	1
3.2.2	dosing manually using temporary mixing tank	1	1	1	3	3	9	1	1	1	1	1	1	3	3	9
3.3	Heat up system to 60 ± 5 °C															
3.3.1	Heating proccess as per 3.1. up to 60 ± 5 °C	3	2	6	4	4	16	3	3	9	1	1	1	3	3	9
3.3.2	Temperature, Alkalinity and pH will be monitored every hour	3	3	9	3	3	9	3	3	9	1	1	1	3	3	9
3.4	Acid stage															
3.4.1	When T = 60 °C close steam injection valve	4	4	16	3	3	9	4	4	16	4	4	16	3	3	9
3.4.2	Dosing citric acid 3%, ammonium bifluoride 0,3% and corrosion inhibitor0,2%	1	1	1	4	4	16	1	1	1	4	4	16	3	3	9
3.4.3	Temperature, acidity, pH, Fe_{3+}, Fe_{tot} y Inhibitor efficiency will be monitored every hour	3	3	9	3	3	9	3	3	9	1	1	1	3	3	9
3.4.4	Check ph is between 3–4	1	1	1	3	3	9	1	1	1	1	1	1	3	3	9
3.4.5	Verify Fe_{tot} remain stable==> end acid stage	1	1	1	3	3	9	1	1	1	1	1	1	3	3	9
3.5	Pasivation stage															
3.5.1	Increase ph up to 7–7.5 dosing NaOH	1	1	1	4	4	16	1	1	1	3	3	9	1	1	1
3.5.2	NaOH must be dosing slowly	1	1	1	3	3	9	1	1	1	1	1	1	3	3	9
3.5.3	Inyectar Nitrito de sodio 0.3% con Ph = 7–7.5	1	1	1	4	4	16	1	1	1	3	3	9	1	1	1
3.5.4	Check temperature is 30–40 °C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3.5.5	Monitor each hour:Temp, pH, Fe_{3+} y Fe_{tot}	3	3	9	3	3	9	3	3	9	1	1	1	3	3	9
3.5.6	Check stability Fe_{3+}	1	1	1	3	3	9	1	1	1	1	1	1	3	3	9

Table A6. Hazard identification and risk assessment for the temporary chemical cleaning system.

System Code Number	Chemical Cleaning One Phase Chapter 7.1	Hazard Evaluation Project Name		Company Logo	
SubSystem	N/A	Cod/Equipment Description		Document Attached	Yes / No
Drawing or Procedure:		Unit:	Method: Structured What-If/Check List	Doc. Type:	
7.1.2.1.- Chemical Cleaning		Light F.O. Chemical Cleaning Procedure	Guide Words Procedure Part II	Not Applicable	
Node: 7.1.2.1.3.- Chemical Cleaning			Description: Light F.O. Chemical Cleaning		

Item	Deviation	Causes	Consequences	Safeguards	Recommendation
3.1.3	Auxiliary Boiler start up from Local Control Panel	Steam pressure of Auxiliary Boiler higher than set point	1.-Overpressure in the boiler, risk of explosion.	1.- Pressure relief valve at the boiler outlet.	1.- To Provide detailed operating instructions for the local operation of the boiler.
	Case: More/Less than			2.- High pressure trip in the boiler. Steam outlet shut-off.	2.- To Provide a list of settings for the Auxiliary Boiler operation, trips and alarms
	Case: Action executed wrongly		2.- Overpressure in the temporary connections to the header. Possible breaking of the temporary hoses with leakage of water at high temperature and pressure.	3.- Shutdown of fuel and steam supply to the system.	
			3.- Potential damage to the people and the environment		
	Caso: More/Less than	See more pressure	See more pressure		
3.1.4	Increase boiler load if required	See more pressure (case 3.1.3.)			
	Case: More/Less than.				
	Action executed wrongly				
3.1.5	Open manual valve for heating header of chemical cleaning solution	Operator open the valve more than necessary	1.- High temperature on return main header	1.-Local thermometer for temperature measurement.	1.-To install an local alarm device (temperature switch) when the temperature rises above the set point.
	Case: More/Less temperature than expected.			2.- Operating instructions	2.- To install a isolation device for T > 70 °C and T = 45 °C for the heating stage.
	Case: Action executed wrongly		2.-Possible breaking of the temporary hoses with leakage of water at high temperature and pressure.		3.- Evaluate the installation of a protection circuit in the local panel to acting on the isolation device for item 2 when overpressure and/or over-temperature happens.
			3.- Potential damage to the people and the environment		

Table A7. Hazard identification and risk assessment for the temporary chemical cleaning system.

System	**Chemical Cleaning One Phase**	**Hazard Evaluation**		**Company Logo**	
Code Number	**Chapter 7.1**	**Project Name**			
SubSystem	**N/A**	**Cod/Equipment Description**		**Document Attached**	**Yes** **No**
Drawing or Procedure:		**Unit:**	**Method: Structured What-If/Check List**	**Doc. Type:**	
7.1.2.1.- Chemical Cleaning		**Light F.O. Chemical Cleaning Procedure**	**Guide Words Procedure Part II**	**Not Applicable**	
Node: 7.1.2.1.3.- Chemical Cleaning			**Description: Light F.O. Chemical Cleaning**		
Item	**Deviation**	**Causes**	**Consequences**	**Safeguards**	**Recommendation**
3.2.1	Dosing surfactant 0.05% and caustic soda 0.25% slowly to temporary mixing tank	Operator dosing more product than required to the temporary mixing tank.	1.- High concentration of degreasing product on the temporary mixing tank	1.-Use of Personal Protective Equipment.	1.- Be sure to regulate the liquid chemical feed flow with the manual pump.
&	Case: More/Less than	1.- More surfactant		2.- For dosing of surfactant (liquid) a pneumatic pump is used.	2.- To provide the quantities to be dosed for caustic soda in order to avoid major mistakes by the operator. Simple data to be provided.
3.2.2	Case: Action executed wrongly	2.- More caustic soda (sodium hydroxide) because operation is manual by emptying bags		3.-Operating Instructions and Safety Data Sheets for chemical products (SDS)	3.- Ensure the emptying from the mixing tank to the effluent basin to recover the degreasing solution.
					4.- Be sure portable eyewash shower is installed.
			2.- pH increasing in the mixed solution.		
			3.- Potential damage to the people and the environment depending of the concentration of the products		
3.3.1	Heating up in accordance with paragraph 3.1 up to 60 ± 5 °C	Operator open the manual valve more than necessary.	1.- High temperature on return main header	1.-Local thermometer for temperature measurement.	1.-To install an local alarm device (temperature switch) when the temperature rises above the set point.
	Case: More/Less temperature than expected.			2.-Design conditions for piping and mechanical equipments.	2.- To install a isolation device for T > 70 °C and T = 45 °C for the heating stage.
	Case: Action executed wrongly		2.-Possible breaking of the temporary hoses with leakage of water at high temperature and pressure.	3.- Operating instructions	3.- Evaluate the installation of a protection circuit in the local panel to acting on the isolation device for item 2 when overpressure and/or over-temperature happens.
			3.- Potential damage to the people and the environment		

After the performance of the risk assessment with the proposed methodology for the presented case study of chemical cleaning, the results that lead to the proposal of additional mitigation measures for the systems are as follows:

- Install pressure safety valves in the circuit to avoid pressures that lead to the failure of the temporary hoses.
- Check the settings and the calibration certificates of the PSVs.
- Install devices for alarm and shutdown in case of too high temperatures. Modify the local panel.
- Install an interlock device in the feeding system of chemical products to the water when steam is being injected.
- Provide the exact quantities of chemical products to be dosed and devices that guarantee their feed.
- Implement checklists that assure the correct performance of the operations. The double-checking of some operations penalizes the execution time and the cost of the number of operators but assures the correct performance of the works.
- Install eye washers in the proximity of the temporary system.

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