Revision July 2012/ editorial corrections August 2013

## Types of safety barriers

Within the (North Sea sector) offshore industry, the concept of "Safety Critical Elements" is used, which are defined according to [3]:

*""safety-critical elements" means such parts of an installation and such of its plant (including computer programmes), or any part thereof—* 

(a) the failure of which could cause or contribute substantially to; or
(b) a purpose of which is to prevent, or limit the effect of,
a major accident."

With reference to this definition, the real "safety barriers" are covered by (b), while (a) refers to "primaryprocess systems". Primary-process systems are the systems that are necessary to perform the primary process, i.e. to store (contain), transport, steer, control, etc., with the only aim to reach the business objective (a product or service). Failure of a (safety-critical) primary-process system is considered as a <u>deviation</u>, which will appear as an <u>initial event</u> in a safety-barrier diagram or bowtie. In this way, a primaryprocess system should not appear in a diagram as a barrier, but actually at the start (left-hand side) of the bowtie/diagram, as the initial deviation is the failure of (or threat to) the primary-process system. Realizing this, one should be careful about considering process containments (wall thickness) or basic process control system (BPCS) as barriers. This is quite in line with the considerations in LOPA ([4], chapter 6) about Independent Layers of Protection (IPL).

It should be understood that a (flawless) system can easily function without safety barriers, but not without the primary-process systems. These considerations may help to determine whether a system or action must be perceived as a safety barrier (defined as (b) above) or not.

The reason for <u>distinguishing</u> the safety barriers and safety critical primary process systems is that the primary process systems operate either continuously or very frequently (weekly, daily, ...) while interventions by safety barriers are rare (once a year or less). It is said that the primary process systems are running in "high demand" mode and safety barriers in "low-demand" mode. This has implications for an assessment of the probability of failure of the systems: primary process systems are "tested" every time they are used, and the human actions which are included in these systems are characterized by a high degree of routine. Safety-barrier reliability in contrast depends on the *planned tests* and *training based on imaginary and predictable events*.

The reason to <u>pool</u> safety barriers and safety critical primary process systems under a single designation (safety-critical elements) is that both are important for process safety, and the underlying tasks of management (safety management) to ensure that safety critical elements are in place and function are the

Nijs Jan Duijm

same namely that they must be maintained and that there is a need for procedures, training, sense of duty, good safety culture, etc.

"Level of Protection Analysis (LOPA)" ([4], Chapter 6) uses a similar separation between the primary process control (controlling to ensure that product meets product requirements) and measures that handle the process deviations that slip through the primary process control. LOPA attaches great importance to the subsequent barrier function being <u>independent</u> of the primary process systems and of each other - only then safety barriers can be perceived as "Independent Layers of Protection (IPL)."

For safety barriers it is also important that they are able to perform their barrier <u>function</u>. This means that they are able to perform the various phases of a defensive action. This defensive action consists of:

- to detect that there is a deviation
- to diagnose what the defensive action must be
- to perform the defensive action

(In LOPA this is called the "DDD" sequence: "Detect, Diagnose, Deflect") A barrier is incomplete if one of these phases, especially to perform the action, is missing. An alarm is not a barrier if there is not an operator who performs the defensive action.

It is emphasized that it is the *actual response*, which constitutes the barrier. In the event of a human action is therefore the *action* itself, not the procedure describing the action ("paper is not a barrier"). But to define a desired action on a given situation by means of a procedure is the way safety managers can improve the likelihood that the desired action be performed when needed, i.e. the procedure (and the quality of the procedures), determine to a high degree the probability of success for a human response. To develop, maintain and train the procedure is an activity of *safety management*.

The following pages describe types of barriers. Safety barriers may be divided into three groups:

- Permanent barriers avert deviations or threats by means of their permanent physical presence, even before the deviation or the threat is materialized. Detection and diagnosis is thus not relevant for those.
- Preventive barriers include actions carried out independently of whether the deviation or threat is materialized. Detection and diagnosis is thus not relevant for those.
- Barriers conducting an intervention in the event of a deviation or threat. These barriers depend on a complete cycle of detection, diagnosis and action.



The safety-barrier types are described on the following pages in a uniform table format. The description includes a reference to safety management issues. The following safety-management issues are used, as defined in [1]:

- Risk analysis and selection of safety barriers
- Learning and management of change
- Manpower planning and availability
- Competence and suitability
- Commitment, compliance and conflict resolution
- Communication and coordination
- Procedures, rules, and goals
- Hard/software purchase, build, interface, install
- Hard/software inspection, maintenance, and replacement

The quality of the management issues that are marked red will affect the quality of the safety barrier (the likelihood that the barrier will be able to perform its barrier function as intended in case of a deviation). The management issues that are marked with a cross are considered to be of special importance. (These markings are derived from the ARAMIS project [1][2]).

For each barrier type a some examples and typical failure modes are included. Please note that the lists of failure modes are not exhaustive; failure modes depend on the individual barrier and the specific conditions, and failure mode identification should be performed systematically for each barrier.

#### References

- [1] Guldenmund, Frank; Hale, Andrew; Goossens, Louis; Betten, Jeroen; Duijm, Nijs Jan, The development of an audit technique to assess the quality of safety barrier management, Journal of Hazardous Materials, Vol.130 Issue.3, 234-241, 2006, ISSN: 03043894, DOI: 10.1016/j.jhazmat.2005.07.011
- [2] Duijm, Nijs Jan; Goossens, Louis; Quantifying the influence of safety management on the reliability of safety barriers, Journal of Hazardous Materials, Issue Vol.130 Issue.3, 284-292, 2006, ISSN 03043894, DOI 10.1016/j.jhazmat.2005.07.014
- [3] The Offshore Installations and Wells (Design and Construction, etc.) Regulations 1996, Statutory Instrument 1996 No. 913, UK Government, ISBN 011054451X, TSO Customer Services, <u>http://www.opsi.gov.uk/si/si1996/Uksi 19960913 en 1.htm#tcon</u> (Regulation 26)
- [4] CCPS/AIChE, Layer of Protection Analysis, Simplified Process Risk Assessment, AIChE, 2001, New York, ISBN 0-8169-0811-7

Title	Excessive	LY CONSERV	VATIVE DES	GIGN AND M	1ECHANICA	L REDUNDA	ANCY					
Detection	Not releva	ant										
Diagnose	Not relevant											
Action	Hardware	: Resiliend	e and red	undancy	withstand	ing physic	al forces					
Description	"Excessive wall thickr the-art or	ely conser ness) are a traditional	vative" m at least a f standards	eans that actor two s used for	the releva more thar that proce	nt charact what wou ess.	eristics of uld be requ	equipmer uired usin	nt (e.g. g state-of-			
	Redundar independe Evaluatior simultane an active barrier).	ncy means ant paths a n of redund ously by a shift to and	that unde and each i dancy mu n acciden other syste	er normal ( path has the st conside t or deviat em must b	conditions he capacit r whether ion (indep be perceive	forces and ty to perfo the redun eendence) ed as an i	e transmit rm the des dant syste . Redunda nterventio	ted throug sired func ems can b incy that r n (i.e. an	gh multiple tion alone. e affected requires active			
Examples	Over-dime double ele	Over-dimensioned wall thickness, fitted with double steering cables or rods, fitted with double electrical connections.										
Failure mechanisms	Material f degradatio following redundan	ailure or i on; proces changes ii t systems.	nstallatior ss conditic n process	n errors, ir ons that ex conditions	n particula kceed eve s; simultar	r followin n so the m neous (cor	g mainten naterial str mmon cau	ance; slov rength, in ise) failure	w particular e of			
Relevant management factors	Risk analysis and selection of safety barriers	Risk analysis and selection of safety barriers Learning and management of change Manpower planning and availability Commetence and availability Communication and comflict resolution Communication and coordination Procedures, rules, and goals Hard/software purchase, build, interface, install Hard/software inspection, maintenance, and replacement										
	Х							Х				

Detection       Not relevant         Diagnose       Not relevant         Action       Hardware: Strength or capacity to handle the deviation or threat.         Description       Passive Barriers are elements in a system that are constantly present (i.e. they do not need to be activated), and that are installed with the only reason to avoid or limit hazardous situations (i.e. the installation can in principle operate without those barriers).         Examples       Tank bunds, dyke, fire protection, drainage sump, fence, lightning conductors, collision barrier, edge protection, hardware protection against body parts entering hazard zones.         Failure mechanisms factors       Lacking strength or capacity, construction error, slow degradation, human error causing flaws (e.g. open rain-water drains in tank bunds), removed (e.g. protection) or not installed or not re-installed after maintenance.         Relevant management factors       U       U       I       <	Title	Permanen	IT PASSIVE	BARRIER									
Diagnose       Not relevant         Action       Hardware: Strength or capacity to handle the deviation or threat.         Description       Passive Barriers are elements in a system that are constantly present (i.e. they do not need to be activated), and that are installed with the only reason to avoid or limit hazardous situations (i.e. the installation can in principle operate without those barriers).         Examples       Tank bunds, dyke, fire protection, drainage sump, fence, lightning conductors, collision barrier, edge protection, hardware protection against body parts entering hazard zones.         Failure mechanisms       Lacking strength or capacity, construction error, slow degradation, human error causing flaws (e.g. open rain-water drains in tank bunds), removed (e.g. protection) or not installed or not re-installed after maintenance.         Relevant management factors       Upper super sup	Detection	Not releva	ant										
Action       Hardware: Strength or capacity to handle the deviation or threat.         Description       Passive Barriers are elements in a system that are constantly present (i.e. they do not need to be activated), and that are installed with the only reason to avoid or limit hazardous situations (i.e. the installation can in principle operate without those barriers).         Examples       Tank bunds, dyke, fire protection, drainage sump, fence, lightning conductors, collision barrier, edge protection, hardware protection against body parts entering hazard zones.         Failure mechanisms       Lacking strength or capacity, construction error, slow degradation, human error causing flaws (e.g. open rain-water drains in tank bunds), removed (e.g. protection) or not installed or not re-installed after maintenance.         Relevant management factors       Unitional activation of the solution o	Diagnose	Not releva	Not relevant										
Description       Passive Barriers are elements in a system that are constantly present (i.e. they do not need to be activated), and that are installed with the only reason to avoid or limit hazardous situations (i.e. the installation can in principle operate without those barriers).         Examples       Tank bunds, dyke, fire protection, drainage sump, fence, lightning conductors, collision barrier, edge protection, hardware protection against body parts entering hazard zones.         Failure mechanisms       Lacking strength or capacity, construction error, slow degradation, human error causing flaws (e.g. open rain-water drains in tank bunds), removed (e.g. protection) or not installed or not re-installed after maintenance.         Relevant management factors       unit use unit case installed or not re-installed after maintenance.       unit use unit case installed after maintenance.         Main dysolftmate installed or not re-installed after maintenance.       unit effects installed or not re-installed after maintenance.       unit use unit case of the structure of the struct	Action	Hardware	: Strength	or capaci	ity to hand	dle the dev	viation or	threat.					
Examples       Tank bunds, dyke, fire protection, drainage sump, fence, lightning conductors, collision parrier, edge protection, hardware protection against pody parts entering hazard zones.         Failure mechanisms       Tacking strength or capacity, construction error, slow degradation, human error causing flaws (e.g. open rain-water drains in tank bunds), removed (e.g. protection) or not installed or not re-installed after maintenance.         Relevant management factors       Communication and conflict resolution and condination and condination and condination and condination and condination and condination         Hard/software inspection, maintenance       Procedures, rules, and solution and maintenance.         Maint continue factors       Manpower planning and management solution and condination and condination and condination and condination         Relevant maintenance       Mard/software inspection, and condination         Maint contract       Manpower planning and management factors installed after maintenance.	Description	Passive Ba need to ba hazardous barriers).	arriers are e activate s situatior	e element d), and th is (i.e. the	s in a syst nat are ins e installati	em that a stalled wit on can in	are consta h the only principle	ntly prese reason to operate w	ent (i.e. th o avoid or ithout the	ney do not · limit ose			
Failure mechanisms       Tacking strendth or cabacity' construction error's and selection of safety barriers of safety barriers of safety barriers or uot installed or uot re-installed alter maintenance.       Failure tearning and management of change       Manpower planning and management of condination       Manpower planning and manpower p	Examples	Tank bund collision b hazard zo	Tank bunds, dyke, fire protection, drainage sump, fence, lightning conductors, collision barrier, edge protection, hardware protection against body parts entering hazard zones.										
Belanation       Selection         A       Risk analysis and selection         of safety barriers       supplement         A       Learning and management         of change       Manpower planning and         Manpower planning and       suitability         Competence and       suitability         Commitment, compliance       and conflict resolution         Procedures, rules, and       coordination         Procedures, rules, and       goals         Hard/software purchase,       build, interface, install         Hard/software inspection,       maintenance, and	Failure mechanisms	Lacking st causing fla or not ins	rength or aws (e.g. talled or r	· capacity, open rain not re-inst	construc water dr alled afte	tion error, ains in tar r mainten	, slow deg nk bunds) ance.	radation, , removed	human e I (e.g. pro	rror otection)			
	Relevant management factors	Risk analysis and selection of safety barriers	Risk analysis and selection of safety barriers Learning and management of change Manpower planning and Competence and suitability Commitment, compliance and conflict resolution Communication and coordination Procedures, rules, and goals Hard/software purchase, build, interface, install Hard/software inspection, maintenance, and replacement										

Title	Permanen	IT BARRIER	: Energizi	Đ								
Detection	The effect active or v	The effect does not depend on the detection of a deviation, but the barrier needs to be active or working.										
Diagnose	Not releva	ant										
Action	Hardware	: capacity	to perfori	m the barı	rier functi	on						
Description	These bar required u	riers are o upon certa	constantly ain conditi	ons, cons	but need ider classi	energy to fication as	) work. If s tempora	activatior Iry barrie	n is r.			
Examples	Forced ve avoid e.g. continuou	Forced ventilation, active corrosion prevention, continuous circulation of material to avoid e.g. hot spots or separation, continuous inerting of systems, pilot flames, continuous addition of inhibitors.										
Failure mechanisms	Not turne supply.	d on/not a	activated,	lacking ca	apacity, la	icking ene	ergy suppl	y or mate	erial (gas)			
Relevant management factors	Risk analysis and selection of safety barriers	Risk analysis and selection         of safety barriers         of safety barriers         Learning and management         of change         Manpower planning and         availability         Competence and         suitability         commitment, compliance         and conflict resolution         ×         Communication and         procedures, rules, and         goals         Hard/software purchase,         build, interface, install         Hard/software inspection,         maintenance, and										

Title	TEMPORA	RY BARRIER	(PASSIVE (	OR ENERGIZ	ZED)							
Detection	The effect present o	The effect does not depend on the detection of a deviation, but the barrier need to be present or working.										
Diagnose	Not releva	Not relevant										
Action	Hardware	: Strength	or capaci	ty to hand	lle the de	viation or	threat.					
Description	Barriers to situation ( locations. rules.	emporary (such as r Installatio	put in pla naintenan on and us	ice or tem ice or repa e depends	iporary us air works) s to a high	ed, deper or within degree c	nding on a a specific on routine	tempora time spa s, proced	ry ns or ures and			
Examples	Barriers a in substar safety clo safety bel systems	Barriers around repair work, blind flanges over open pipes, spades in pipes, inhibitors in substances, personal protection equipment (PPE: e.g. hard hats, safety goggles, safety clothing, safety gloves), clothes and shoes to avoid static electricity, fixed safety belt (as in a plane), earthing of tanks during (un)loading, mechanical lock-out systems										
Failure mechanisms	Not put in pressure)	place, no , wrongly	ot donned mounted.	(PPE), no	t appropr	iate for th	e hazard	(chemica	ls, heat,			
Relevant management factors	Risk analysis and selection of safety barriers	Risk analysis and selection of safety barriers Learning and management of change Manpower planning and availability Competence and availability Competence and suitability Commitment, compliance and conflict resolution Communication and coordination Procedures, rules, and goals Hard/software purchase, build, interface, install Hard/software inspection, maintenance, and replacement										
			X				X		X			

Title	RESPECT SAFETY ZONES AND WARNINGS											
Detection	Detection as regards	relates to s to devia	warnings tions).	s and sign	s, not to a	detection	of deviatio	ons (pass	ive barrier			
Diagnose	Not relevant											
Action	Behaviour and refrai	Behaviour: To respect markings and warning signs: refrain from entering danger zones and refrain from manipulating marked parts of installations.										
Description	Symbols, refrain fro touching, prevents p Awarenes operation Note that Note that part of a r interface a	Symbols, markings and warning signs (passive, i.e. not alarms) request to perform or refrain from certain behaviour. Implies in general refraining from certain actions (not touching, not operating, not entering, not smoking). Respecting danger zones prevents people from getting hurt when deviations occur (mitigating barrier). Awareness of valves closing off dangerous substances may prevent erroneous operation. Note that the barrier consists of the behaviour itself, not the signalling. Note that marking components such as valves in order to support correct operation is part of a management obligation to provide a sufficiently good human-machine interface and work place rather than a safety barrier.										
Examples	Not enter machinery smoking p	Not entering danger zones (e.g. at cranes or robot stations, open containers, rotating machinery) , refrain from operating valves, avoid contact with hot parts, respecting smoking prohibitions, obeying speed limits.										
Failure mechanisms	Not respe work task	cting sign s.	s and ma	rkings, lac	king sign:	s, unclear	signs, an	d conflict	s with			
Relevant management factors	Risk analysis and selection of safety barriers	Risk analysis and selection of safety barriers Learning and management of change Manpower planning and availability Competence and availability Competence and suitability Communication and communication and coordination Procedures, rules, and goals Hard/software purchase, build, interface, install Hard/software inspection, maintenance, and replacement										
	X				Х		X					

Detection         Detection concerns attention to situations where the preventive action is required according to procedure, the deviation or threat is not detected.           Diagnose         Not relevant           Action         Behaviour or hardware: To follow rules and procedures which apply to the situation at hand or (activate) automated sequencing through steps in a process.           Description         The activity is performed as part of a procedure for some operation or step in a process in order to prevent dangerous situations, even when the dangerous situation not necessarily is present. There may be overlap with "Temporary barrier" (e.g. making a ground connection and leaving it in place during the (un)loading), but this barrier type focuses on actions performed prior to the hazardous activity, i.e. detached in time.           Examples         Venting of closed spaces before entering, venting/emptying hoses before detachment, earthing tankers before (un)loading to prevent static electricity, inerting vessels or reactors before taking into use.           Failure mechanisms         Image uning the action, incomplete or faulty execution.           Relevant management factors         Uning the action, incomplete or faulty execution.	Title	Preventiv	'E PROCEDU	JRAL ACTIC	DN								
Diagnose         Not relevant           Action         Behaviour or hardware: To follow rules and procedures which apply to the situation at hand or (activate) automated sequencing through steps in a process.           Description         The activity is performed as part of a procedure for some operation or step in a process in order to prevent dangerous situations, even when the dangerous situation not necessarily is present.           There may be overlap with "Temporary barrier" (e.g. making a ground connection and leaving it in place during the (un)loading), but this barrier type focuses on actions performed prior to the hazardous activity, i.e. detached in time.           Examples         Venting of closed spaces before entering, venting/emptying hoses before detachment, earthing tankers before (un)loading to prevent static electricity, inerting vessels or reactors before taking into use.           Failure mechanisms         Not executing the action, incomplete or faulty execution.           Relevant management factors         Unit(t) unit tartace in the state incomplete or faulty execution.	Detection	Detection according	Detection concerns attention to situations where the preventive action is required according to procedure, the deviation or threat is not detected.										
Action       Behaviour or hardware: To follow rules and procedures which apply to the situation at hand or (activate) automated sequencing through steps in a process.         Description       The activity is performed as part of a procedure for some operation or step in a process in order to prevent dangerous situations, even when the dangerous situation not necessarily is present. There may be overlap with "Temporary barrier" (e.g. making a ground connection and leaving it in place during the (un)loading), but this barrier type focuses on actions performed prior to the hazardous activity, i.e. detached in time.         Examples       Venting of closed spaces before entering, venting/emptying hoses before detachment, earthing tankers before (un)loading to prevent static electricity, inerting vessels or reactors before taking into use.       Not executing the action, incomplete or faulty execution.         Relevant management factors       Utility interuge: instead of a goals       Not executing the action, incomplete or faulty execution.	Diagnose	Not relevant											
Description       The activity is performed as part of a procedure for some operation or step in a process in order to prevent dangerous situations, even when the dangerous situation not necessarily is present. There may be overlap with "Temporary barrier" (e.g. making a ground connection and leaving it in place during the (un)loading), but this barrier type focuses on actions performed prior to the hazardous activity, i.e. detached in time.         Examples       Venting of closed spaces before entering, venting/emptying hoses before detachment, earthing tankers before (un)loading to prevent static electricity, inerting vessels or reactors before taking into use.         Failure mechanisms       Not executing the action, incomplete or faulty execution.         Relevant factors       Not executing the action, incomplete or faulty execution.         management factors       unithenument of goals         maintenance, and multication and condition       unithenument         List performance instant       Not executing the action, incomplete or faulty execution.         Methods       maintenance, and multication and condition and conditin and condition and conditin and condition and	Action	Behaviour hand or (a	r or hardw activate) a	vare: To fo utomated	llow rules I sequenci	and proc ng throug	edures wh h steps in	nich apply a process	to the sit	uation at			
Examples       Venting of closed spaces before entering, venting/emptying hoses before detachment, earthing tankers before (un)loading to prevent static electricity, inerting vessels or reactors before taking into use.         Failure mechanisms       Not executing the action, incomplete or family and management factors         Relevant management factors       Not executing the action, incomplete or family availability         Procedures, rules, and conflict resolution       Communication and conflict resolution         Brond goals       Procedures, rules, and solution         Iterative maintenance, and maintenance, and conflict resolution       Communication and conflict resolution         Iterative management factors       Iteration         Iterative management factors       Communication and conflict resolution         Iteration       Devocadures, rules, and conflict resolution         Iterat/software inspection, interface, install       Iteration         Iteration       Iteration	Description	The activi process in not neces There ma leaving it performed	ty is perfo order to sarily is p y be overl in place d d prior to	prevent d prevent d resent. lap with <sup>***</sup> luring the the hazar	part of a p langerous Temporar (un)loadi dous activ	orocedure situations y barrier" ng), but t rity, i.e. d	for some s, even wl (e.g. mak his barrier etached ir	operation nen the da king a grou r type focu n time.	n or step i angerous und conn uses on a	n a situation ection and ctions			
Eailure mechanismNot execritionRisk analysis and selection of safety barriers of safety barriers Manpower planning and management of change Manpower planning and maintensNot execution of safety barriers Manpower planning and management of change Manpower planning and maintenseNot exection management availability Manpower planning and maintense maintenseNot exection maintense maintenseNot execution maintense maintenseNot execution maintense maintenseNot execution maintense maintenseNot execution maintense maintenseNot execution maintenseNot execution maintenseHard/software main	Examples	Venting or earthing t reactors b	Venting of closed spaces before entering, venting/emptying hoses before detachment, earthing tankers before (un)loading to prevent static electricity, inerting vessels or reactors before taking into use.										
Belevation       state of safety barriers         Risk analysis and selection       of safety barriers         Risk analysis and selection       safety barriers         Rearning and management       of change         Manpower planning and management       suitability         Competence and availability       compliance         Manpower planning and management       suitability         Commitment, compliance       and conflict resolution         Procedures, rules, and goals       Procedures, rules, and goals         Hard/software purchase, build, interface, install       Hard/software inspection, maintenance, and replacement	Failure mechanisms	Not execu	iting the a	action, inc	omplete c	or faulty e	xecution.						
X X X X	Relevant management factors	<ul> <li>Risk analysis and selection</li> <li>of safety barriers</li> </ul>	<ul> <li>Risk analysis and selection of safety barriers</li> <li>Learning and management of change</li> <li>Manpower planning and availability</li> <li>Manpower planning and availability</li> <li>Competence and suitability</li> <li>Commitment, compliance and conflict resolution</li> <li>Communication and coordination</li> <li>Procedures, rules, and goals</li> <li>Hard/software purchase, build, interface, install</li> <li>Hard/software inspection, maintenance, and replacement</li> </ul>										

Detection +	Hardware				HARDWARE INTERVENTION										
		Hardware													
Diagnose +	Hardware														
Action +	Hardware														
Description B	Barriers th deviation a	nat by me and perfo	ans of dir rm the ne	ect mecha cessary a	anical-phy ction.	rsical princ	ciples both	n detect t	he						
<b>Examples</b> P n	Pressure r mechanisr	elief valve n in mode	es, burstin ern safety	g disks, sp belts in ca	orinkler he ars	ads, explo	sion relie	f hatches	, blocking						
Failure <sup>I</sup> mechanisms <sup>t</sup>	Insufficien towards th	t capacity ne barrier	y (too sma ), stuck o	all, too slo r other mo	ow), wrong echanical	g set poin defects.	t, blocked	(includir	g piping						
Relevant management factors	Risk analysis and selection of safety barriers Learning and management of change Manpower planning and availability Competence and suitability Commitment, compliance and conflict resolution Communication and coordination Procedures, rules, and goals Hard/software purchase, build, interface, install Hard/software inspection, maintenance, and replacement														

Title	Αυτοματι	AUTOMATED INTERVENTION/SAFETY INSTRUMENTED SYSTEM (SIS)										
Detection	Hardware											
Diagnose	Hardware	Hardware/software										
Action	Hardware											
Description	Automate (E/E/EP) o what inter perform tl In order fo barrier (in system sh	d interver componer rvention n his interve or an auto ndepender nould not	ntion by a lits, that o leeds to b ention. omated sy nt protecti be part of	system o n the basi e made, a ystem to b ion layer) the basic	f electrica is of input and activa e conside the comp process o	I/electron from sen tes actuat red to be onents th control sys	ic/program sors is ab cors (like p an indepe at make u stem (BPC	mmable e le to dete powered v endent sa up the aut CS).	electronic ermine valves) to fety comated			
Examples	Emergenc	y shutdov	vn system	(ESD), en	nergency b	olowdown	system, a	airbag in a	a car.			
Failure mechanisms	Componei failure, co	nt failure ommon ca	(sensors, use failure	electronic e	circuits a	and actuat	cors), soft	ware failu	ıre, design			
Relevant management factors	<ul> <li>Risk analysis and selection</li> <li>of safety barriers</li> </ul>	<ul> <li>Risk analysis and selection of safety barriers</li> <li>Learning and management of change</li> <li>Manpower planning and availability</li> <li>Competence and suitability</li> <li>Commitment, compliance and conflict resolution</li> <li>Communication and coordination</li> <li>Procedures, rules, and goals</li> <li>Hard/software purchase, build, interface, install</li> <li>Hard/software inspection, maintenance, and replacement</li> </ul>										

Title	HUMAN IN	TERVENTIC	N FOLLOW	ING ALARN	1							
Detection	Hardware	/software										
Diagnose	Behaviou	Behaviour according to clear procedures ("Skill & Rule based")										
Action	Behaviour of powere	r accordin ed compor	g to clear nents)	procedure	es ("Skill &	Rule base	ed") (may	include a	ctivation			
Description	Actions of clear instr the alarm In order for (indepence should no	operators fuctions de s. The ser or the ala lent prote t be part	s in respo escribing nsors, trai rm systen ction laye of the bas	nse to cle the action nsmitters n to be co r) the con sic process	ar instrun is that are and actua nsidered nponents s control s	nent signa e required tors are p to be an in that make system (Bl	als or alarn to respon part of the ndepender e up the a PCS).	ms. There d to the e barrier s nt safety larm syst	e will be each of ystem. barrier em			
Examples	Manual sh (correct)	Manual shutdown or adjustment, evacuation, calling fire brigade on alarm, close/open (correct) valve										
Failure mechanisms	Failure of operator i	sensors, i not preser	transmitte nt.	ers or soft	ware, flav	vs in instr	uctions, w	rong inte	rvention,			
Relevant management factors	Risk analysis and selection of safety barriers	Risk analysis and selection of safety barriers Learning and management of change Manpower planning and availability Competence and suitability Commitment, compliance and conflict resolution Communication and coordination Procedures, rules, and goals Hard/software purchase, build, interface, install Hard/software inspection, maintenance, and replacement										

Title	SITUATION	AL HUMAN	I INTERVEN	TION (PRO	CEDURAL)							
Detection	Human o	bservatio	n and inte	rpretatior	1							
Diagnose	Behaviou	Behaviour according to clear procedures ("Skill & Rule based")										
Action	Behaviou	r accordin	g to clear	procedure	es ("Skill 8	Rule base	ed")					
Description	The hazar in accorda hazardous failure can failure in failure. This barrie	dous situa ance with s situatior n both be the sense er also ind	ation is de clear rule n needs to considere that a de cludes act	etected by s and pro- be derive d to be a viation do ions of su	human o cedures. T ed from a part of th pes not sh pervisors	bservatio There are combinati e initiatin ow up) or supervisir	n of (a con no clear a ion of inpu g deviatio as part o ng other o	mbinatior larms, th ıts. Instru n (a dan <u>c</u> f the barr perator's	n) factors e ument jerous ier tasks.			
Examples	To adjust tanks, hos fighting w	To adjust hardware set-points, to warn others for action or evacuation, to disconnect tanks, hoses or pipes, to avoid escalation protection equipment with foam or fire-fighting water.										
Failure mechanisms	Failure of interventi	instrume on.	nts or soft	ware, flav	ws in instr	uction, la	ck of atter	ntion, wro	ong			
Relevant management factors	<ul> <li>Risk analysis and selection</li> <li>of safety barriers</li> </ul>	<ul> <li>Risk analysis and selection of safety barriers</li> <li>Learning and management of change</li> <li>Manpower planning and availability</li> <li>Manpower planning and availability</li> <li>Competence and suitability</li> <li>Commitment, compliance and conflict resolution</li> <li>Communication and coordination</li> <li>Procedures, rules, and goals</li> <li>Hard/software purchase, build, interface, install</li> <li>Hard/software inspection, maintenance, and replacement</li> </ul>										

Title	KNOWLEDG	GE-BASED H	IUMAN INT	ERVENTIO	N (AD HOC)	)						
Detection	Human o	bservatior	n and inte	rpretatior	).							
Diagnose	Behaviour	Behaviour on the basis of knowledge and reasoning ("Knowledge based")										
Action	Behaviour											
Description	Interventi (e.g. durin procedure This barrie barrier (en prevention supported	on that re ng a rescu ss or rules er type is mergency n of foreso I by proce	equires a d le operation apply. provided response eeable con dures, i.e	continuou on) and/o for sake c ) at the fa nditions si . "Rule an	s knowled r requires of complet ar right-ha hould be o d Skill-ba	lge-based detailed reness. Ap and side o dealt with sed″ barri	assessme analysis ir part from u of the diag by preme iers.	ent of the n cases w use as a r ram or bo ditated a	situation here no nitigating ow-tie, ctions,			
Examples	Fire-fighti as a nucle	Fire-fighting, emergency response, to (re)gain control over a complex system (such as a nuclear reactor) and bring it to a safe condition.										
Failure mechanisms	Wrong ass early.	sessment	and diagr	nosis, inac	lequate ir	Iterventio	n, interver	ntion too	late, too			
Relevant management factors	Risk analysis and selection of safety barriers	Risk analysis and selection of safety barriers Learning and management of change Manpower planning and availability Competence and availability Comment, compliance and conflict resolution communication and coordination Procedures, rules, and goals Hard/software purchase, build, interface, install Hard/software inspection, maintenance, and replacement										
			X	X		X						