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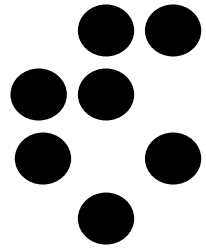

RISK COMPARISON OF METHODS FOR DEPENDENCY DETERMINATION WITHIN HUMAN RELIABILITY ANALYSIS

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Contents

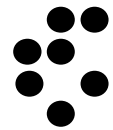
PSAM9, Hong Kong, May 19, 2008

INTRODUCTION

Human reliability analysis is a systematic framework, which includes the process of evaluation of human performance and associated impacts on structures, systems and components for a complex facility.

The contribution of human reliability analysis to the reliability of a complex system and to the safety of nuclear power plants, which is mostly assessed by probabilistic safety assessment, is large (Čepin & Mavko 2005).

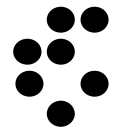
Consideration of dependencies between consecutive human failure events within an accident sequence is an important issue, which impacts the results of probabilistic safety assessment (Čepin & Mavko 2005).



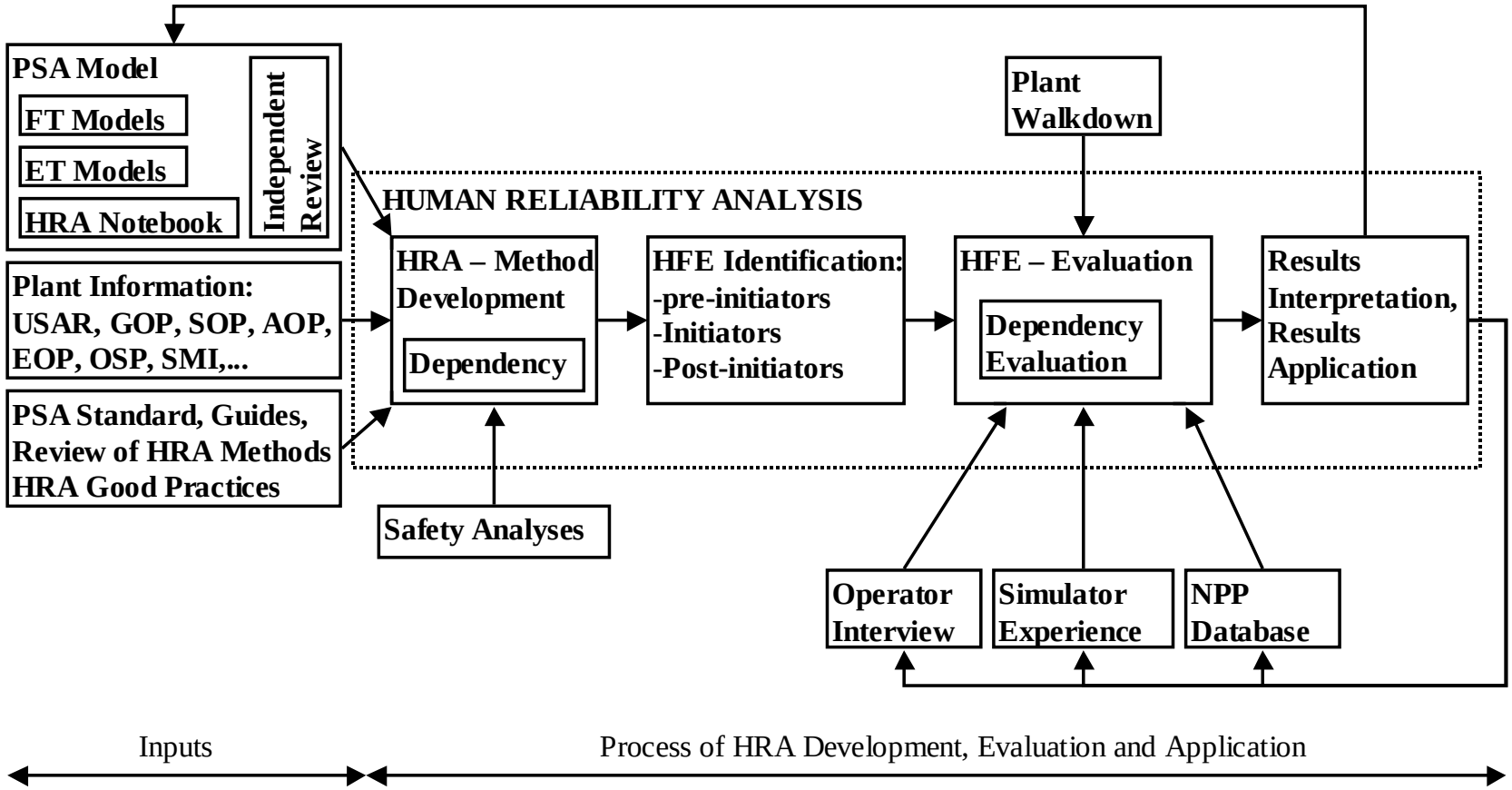
OBJECTIVE

The objective of the paper is to show that subjectivism can largely impact the human reliability analysis (HRA) results and consequently the results and applications of probabilistic safety assessment (PSA) in a nuclear power plant (NPP).

The objective is to identify the key features, which may decrease of subjectivity of HRA.



IJS-HRA METHOD



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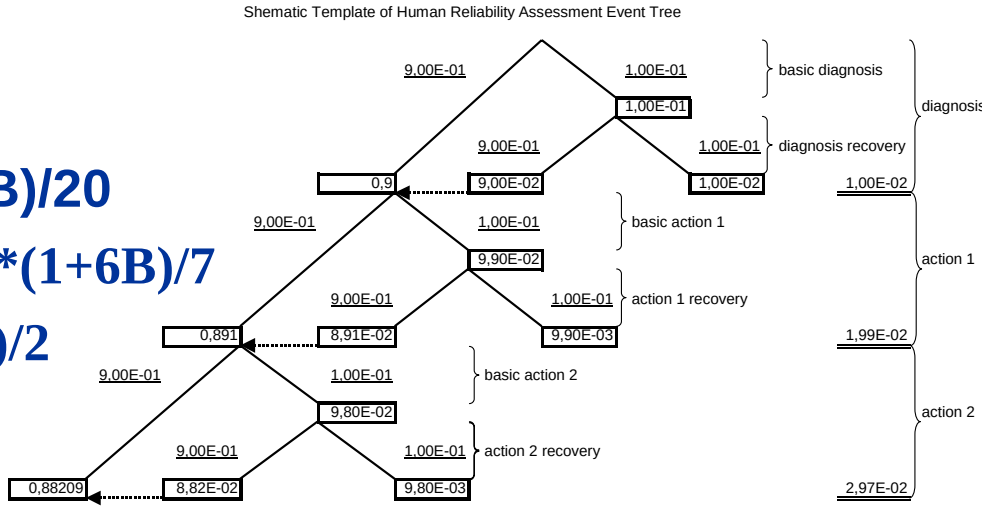
CONSIDERATION OF DEPENDENCIES

Consideration of dependencies between human failure events

- the dependencies between tasks of human actions within one basic event, i.e. one human failure event, can be considered and
- the dependencies between separate human failure events can be considered

DEPENDENCE LEVELS:

- zero dependence (ZD): $P_{ZD}(F)=A*B$
- low dependence (LD): $P_{LD}(F)=A*(1+19B)/20$
- moderate dependence (MD): $P_{MD}(F)=A*(1+6B)/7$
- high dependence (HD): $P_{HD}(F)=A*(1+B)/2$
- complete dependence (CD): $P_{CD}(F)=A$



Branch data are underlined (success probability is calculated: 1- failure probability).
Success - left; failure - right.
Steps are modeled consequently one after another.
Each step include recovery of its action as independent event.
If recovery is not considered as part of its particular step,
write its success probability as 0 and its failure probability as 1.
Double underlined are the results: sum of failure probabilities
of all failure scenarios.

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EVALUATION OF DEPENDENCE BETWEEN HFE FOR PRE-INITIATORS

- SYSTEM: parallel or sequential system
- PERSON: the same person is performing the event or different person is performing the event,
- ACTION_DESCRIPTION: calibration or alignment
- PROCEDURE: the same (or very similar) or different procedure
- TIMING: within 10 minutes after the previous event (or more time),
- ACTION_SIMILARITY: which distinguishes between similar or not similar event; in the case of alignment this is related to the same or different visual frame of the event; in the case of calibration this is related to same or different calibration tool used for the event,
- CONDITION: which is an additional parameter, which allows to limit joined probability of dependent HEPs to be lower as predetermined limit, if there is no justification for low joined HEP.

+ GEOMETRY AVERAGE

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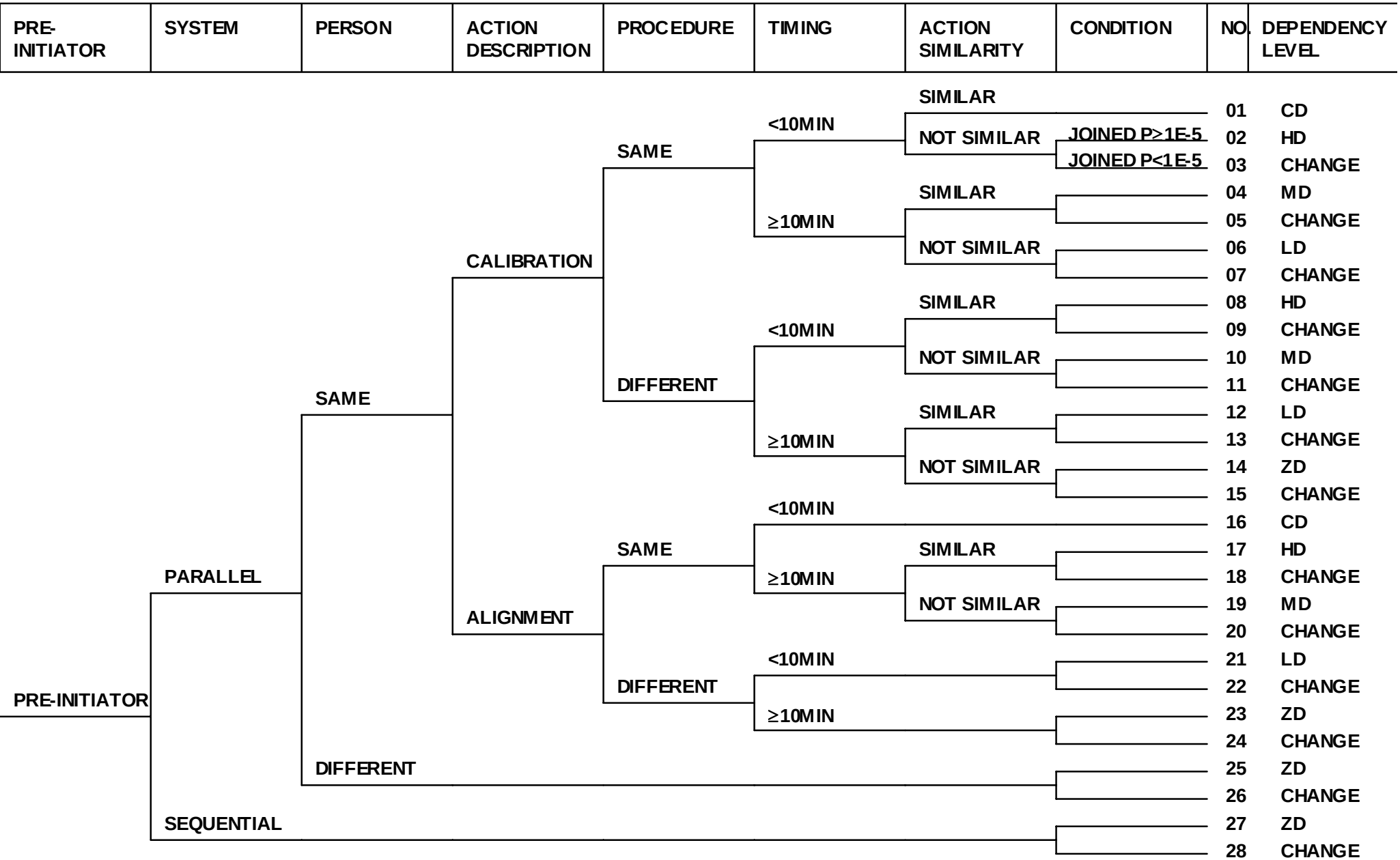
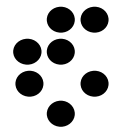
DEPENDENCY - PRE-INITIATORS



PRE-INITIATOR	SYSTEM	PERSON	ACTION DESCRIPTION	PROCEDURE	TIMING	ACTION SIMILARITY	CONDITION	NO.	DEPENDENCY LEVEL
PRE-INITIATOR	PARALLEL	SAME	CALIBRATION	SAME	<10MIN	SIMILAR		01	CD
						NOT SIMILAR	JOINED P>1E-5	02	HD
							JOINED P<1E-5	03	CHANGE
					≥10MIN	SIMILAR		04	MD
						NOT SIMILAR		05	CHANGE
								06	LD
								07	CHANGE
				DIFFERENT	<10MIN	SIMILAR		08	HD
								09	CHANGE
						NOT SIMILAR		10	MD
								11	CHANGE
					≥10MIN	SIMILAR		12	LD
								13	CHANGE
						NOT SIMILAR		14	ZD
								15	CHANGE
			ALIGNMENT	SAME	<10MIN			16	CD
					≥10MIN	SIMILAR		17	HD
								18	CHANGE
						NOT SIMILAR		19	MD
								20	CHANGE
				DIFFERENT	<10MIN			21	LD
								22	CHANGE
					≥10MIN			23	ZD
								24	CHANGE
		DIFFERENT						25	ZD
								26	CHANGE
	SEQUENTIAL							27	ZD
								28	CHANGE

EVALUATION OF DEPENDENCE BETWEEN HFE FOR POST-INITIATORS

- SYSTEM: parallel or sequential system compared to previous event
- CUE: diagnosis: common or different
- TIME_BETWEEN: less than 5 minutes or as more than 5 minutes but less than 30 minutes or more than 30 minutes
- CREW: the same crew or different crew is performing the event
- STRESS: three levels of stress: high, moderate and low
- COMPLEXITY: complex or simple
- CONDITION: which is an additional parameter, which allows to limit joined probability of dependent HEPs to be lower as predetermined value (e.g. 1E-5), if there is no justification for low joined HEP.



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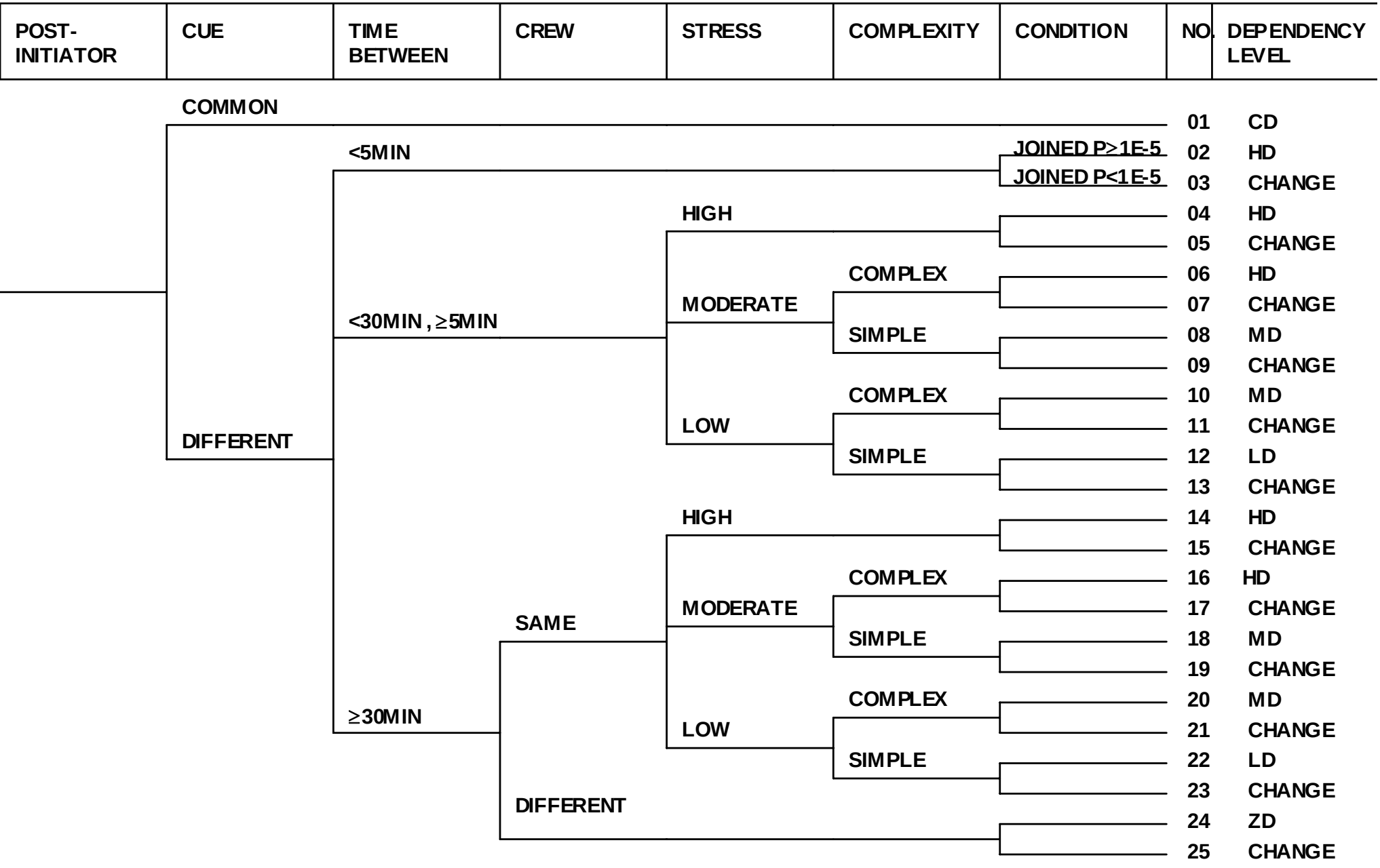
DEPENDENCY - POST-INITIATORS



DEPENDENCY IN OTHER METHODS

ASEP NOMINAL HRA	SERIES SYSTEM	ERROR OF COMMISSION	ACTIONS ON DIFFERENT COMPONENTS IN 2 MINUTES	ACTIONS WITHIN SAME VISUAL FRAME OF REFERENCE	OPERATOR REQUIRED TO WRITE SOMETHING FOR EACH COMPONENT	ACTIONS ON DIFFERENT COMPONENTS WITHIN SAME GENERAL AREA			
ASEP-NOM-PRE-I	SERIES	E_COM	SHORT_T	VISUAL	WRITE	DIF_COMP			
							1		ZD
							2		ZD
							3		CD
							4		ZD
							5		HD
							6		N/A
							7		ZD

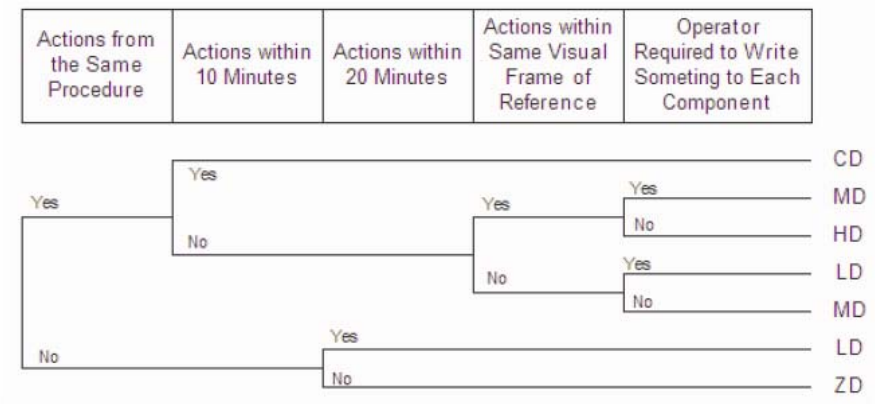
ASEP PRE-INITIATORS

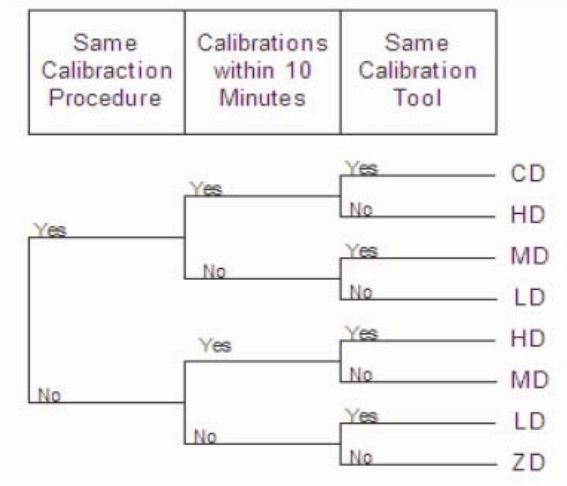
EPRI HRA (PSA05)

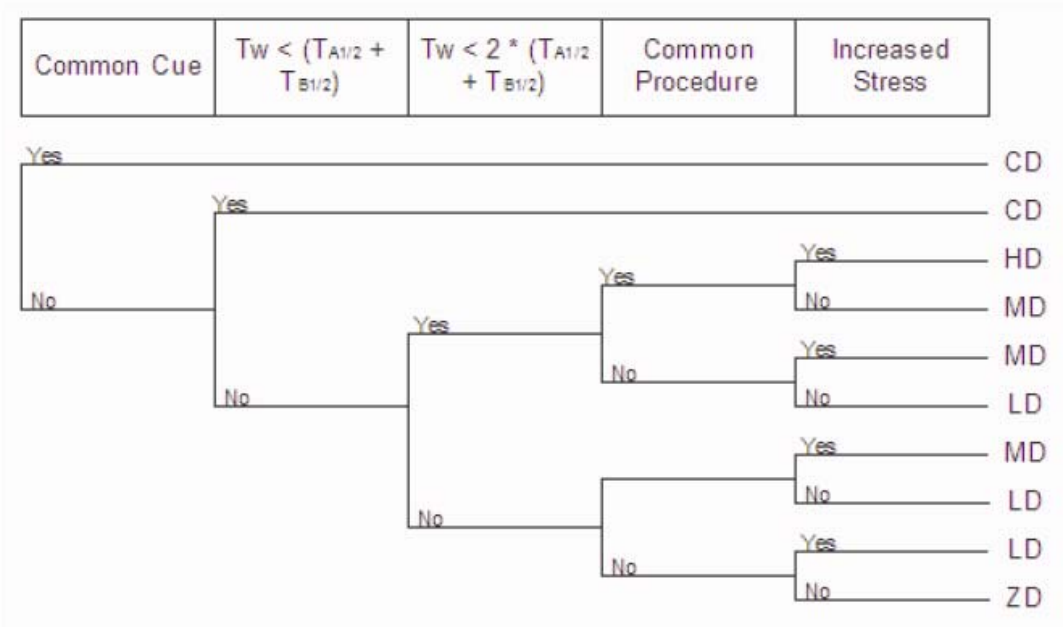
Time between cues	Adequate Resources	Stress	Level
Simultaneous	No	High	CD
		Low	
	Yes	High	CD
		Low	HD
0-15 min.	Yes	High	CD
		Low	HD
15 to 30 min.	Yes	High	HD
		Low	MD
30 to 60 min.	Yes	High	MD
		Low	LD
> 60 min.	Yes	High	LD
		Low	ZD

DEPENDENCY IN OTHER METHODS

SURRY



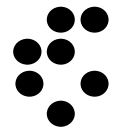




DEPENDENCY IN OTHER METHODS

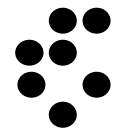
SPAR-H

Condition Number	Crew (same or different)	Time (close in time or not close in time)	Location (same or different)	Cues (additional or no additional)	Dependency	Number of Human Action Failures Rule ☐ - Not Applicable. Why?_____
1	s	c	s	na	complete	When considering recovery in a series e.g., 2nd, 3rd, or 4th checker If this error is the **3rd error in the sequence**, then the dependency is at least **moderate**. If this error is the **4th error in the sequence**, then the dependency is at least **high.**
2				a	complete	
3			d	na	high	
4				a	high	
5		nc	s	na	high	
6				a	moderate	
7			d	na	moderate	
8				a	low	
9	d	c	s	na	moderate	
10				a	moderate	
11			d	na	moderate	
12				a	moderate	
13		nc	s	na	low	
14				a	low	
15			d	na	low	
16				a	low	
17					zero	



QUALITATIVE COMPARISON: IJS-HRA AND SPAR-H

Pre-Initiators		Post-Initiators		
IJS-HRA	**SPAR-H**	**IJS-HRA**	**SPAR-H**	
CD1	CD1, HD3	CD1	CD1, HD3, HD5, MD7, MD9, MD11, LD13, LD15	Increase of initially determined dependency due to larger number of consecutive actions in a sequence
HD2	CD2, HD4	HD2	CD2, HD4, MD10, MD12	
MD4	HD5, MD7	HD4	CD2, HD4, MD6, LD8, MD10, MD12, LD14, LD16	
LD6	MD6, LD8	HD6	CD2, HD4, MD6, LD8, MD10, MD12, LD14, LD16	
HD8	CD1, HD3	MD8	CD2, HD4, MD6, LD8, MD10, MD12, LD14, LD16	
MD10	CD2, HD4	MD10	CD2, HD4, MD6, LD8, MD10, MD12, LD14, LD16	
LD12	HD5, MD7	LD12	CD2, HD4, MD6, LD8, MD10, MD12, LD14, LD16	
ZD14	MD6, LD8	HD14	MD6, LD8	
CD16	CD1, CD2, HD3, HD4	HD16	MD6, LD8	
HD17	HD5, MD7	MD18	MD6, LD8	
MD19	MD6, LD8	MD20	MD6, LD8	
LD21	CD1, CD2, HD3, HD4	LD22	MD6, LD8	
ZD23	HD5, MD6, MD7, LD8	ZD24	LD14, LD16	
ZD25	MD9, MD10, MD11, MD12, LD13, LD14, LD15, LD16			
ZD27	CD1, CD2, HD3, HD4, HD5, MD6, MD7, LD8, MD9, MD10, MD11, MD12, LD13, LD14, LD15, LD16			



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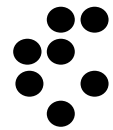
DEPENDENCY - POST-INITIATORS

POST-INITIATOR	CUE	TIME BETWEEN	CREW	STRESS	COMPLEXITY	CONDITION	NO.	DEPENDENCY LEVEL
COMMON							01	CD
		<5MIN				JOINED P≥1E-5	02	HD
						JOINED P<1E-5	03	CHANGE
				HIGH			04	HD
							05	CHANGE
				MODERATE	COMPLEX		06	HD
							07	CHANGE
		<30MIN , ≥5MIN			SIMPLE		08	MD
							09	CHANGE

Condition Number	Crew (same or different)	Time (close in time or not close in time)	Location (same or different)	Cues (additional or no additional)	Dependency	Number of Human Action Failures Rule ☐ - Not Applicable. Why?_____
1	s	c	s	na	complete	When considering recovery in a series e.g., 2nd, 3rd, or 4th checker If this error is the **3rd error in the sequence**, then the dependency is at least **moderate**. If this error is the **4th error in the sequence**, then the dependency is at least **high.**
2				a	complete	
3			d	na	high	
4				a	high	
5		nc	s	na	high	
6				a	moderate	
7			d	na	moderate	
8				a	low	
9	d	c	s	na	moderate	
10				a	moderate	
11			d	na	moderate	
12				a	moderate	
13		nc	s	na	low	

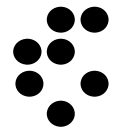
QUALITATIVE COMPARISON: IJS-HRA AND SPAR-H

Pre-Initiators		Post-Initiators		
IJS-HRA	**SPAR-H**	**IJS-HRA**	**SPAR-H**	
LD12+calculation [1,4]	HD5	CD1	CD1	
HD17+calculation [1,4]	HD5	HD2	CD2, MD12	
		MD8	HD4, LD8	
		MD18	LD8	
		MD20	LD8	
		LD12	LD8	MD-3th-in-sequence
Example row->		LD22	MD6, LD8	MD-3th-in-sequence, HD-4th-in-sequence
		ZD24	LD14, LD16	MD-3th-in-sequence, HD-4th-in-sequence



QUANTITATIVE COMPARISON: IJS-HRA AND SPAR-H

BASIC EVENT ID	DEPENDENCY LEVEL IJS-HRA	FINAL HEP IJS-HRA	DEPENDENCY LEVEL SPAR-H	FINAL HEP SPAR-H
PRE_INI_01	CALC, IND, LD12	1,91E-03	HD5	5,00E-01
PRE_INI_02	CALC, IND, LD12	1,91E-03	HD5	5,00E-01
POST_INI_34	ZD24	4,52E-03	LD16	5,43E-02
POST_INI_42	MD8	1,71E-01	LD8	8,08E-02
POST_INI_53	ZD24	1,58E-02	LD14	6,50E-02
POST_INI_63	LD22	5,07E-02	HD-4th-in-seq	5,00E-01
POST_INI_66	HD2	5,16E-01	MD12	1,70E-01
POST_INI_69	ZD24	1,04E-03	LD14	5,10E-02
POST_INI_79	ZD24	1,96E-04	MD-3th-in-seq	1,43E-01

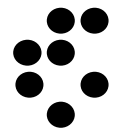


QUANTITATIVE COMPARISON OF RESULTS: IJS-HRA AND SPAR-H

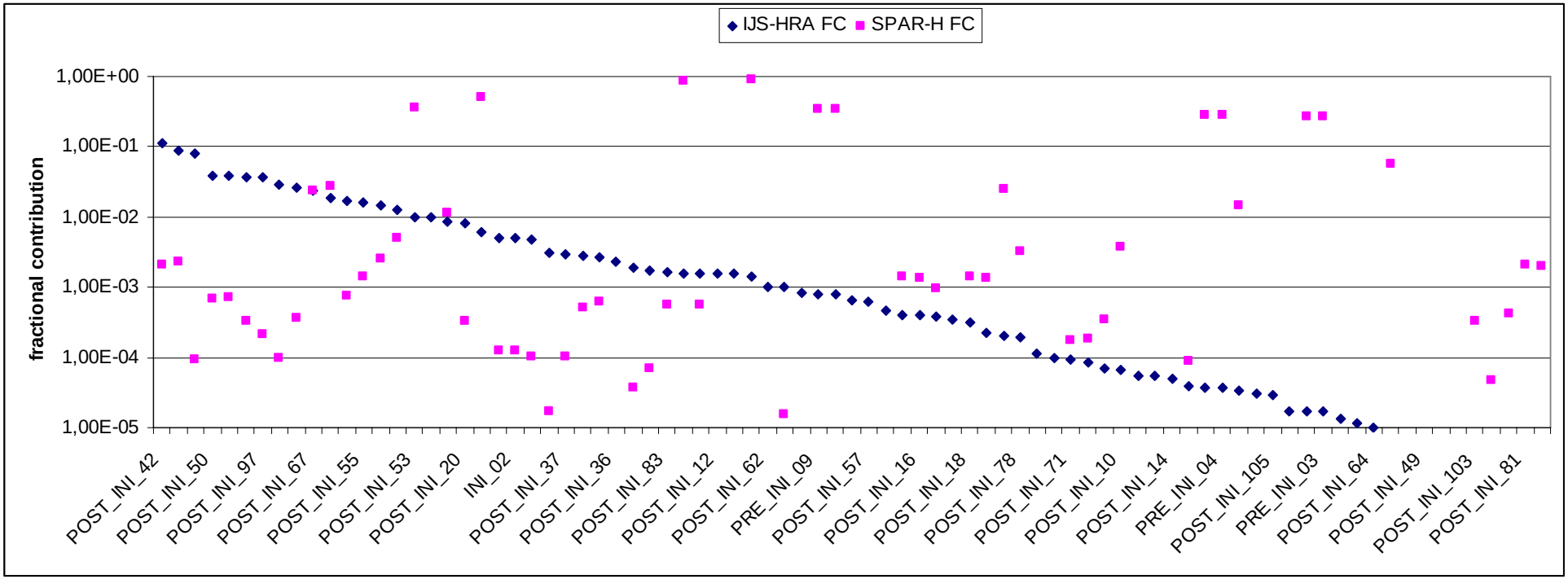
PSA MODEL BASED ON HEP OF HFE DETERMINED BY IJS-HRA			
HFE	**RDF**	**HFE**	**RIF**
POST_INI_42	1,13E+00	POST_INI_04	2,26E+02
POST_INI_63	1,09E+00	POST_INI_12	7,46E+01
POST_INI_88	1,09E+00	POST_INI_100	4,49E+01
		POST_INI_95	3,66E+01
		INI_01	2,34E+01
		INI_02	2,34E+01
		POST_INI_102	2,23E+01
		POST_INI_02	1,75E+01
		POST_INI_34	6,73E+00
		POST_INI_35	3,19E+00
		POST_INI_69	2,68E+00
		POST_INI_63	2,62E+00
		POST_INI_60	2,01E+00

PSA MODEL BASED ON HEP OF HFE DETERMINED BY SPAR-H			
HFE	**RDF**	**HFE**	**RIF**
PRE_INI_06	1,01E+01	POST_INI_53	5,76E+00
PRE_INI_05	8,18E+00	POST_INI_04	5,63E+00
POST_INI_102	2,07E+00		
POST_INI_53	1,55E+00		
PRE_INI_09	1,51E+00		
PRE_INI_10	1,51E+00		
PRE_INI_04	1,40E+00		
PRE_INI_01	1,40E+00		
PRE_INI_02	1,38E+00		
PRE_INI_03	1,38E+00		
POST_INI_79	1,06E+00		

Only POST_INI_04 is found on both listings



COMPARISON OF FRACTIONAL CONTRIBUTION OF HFE: IJS-HRA AND SPAR-H



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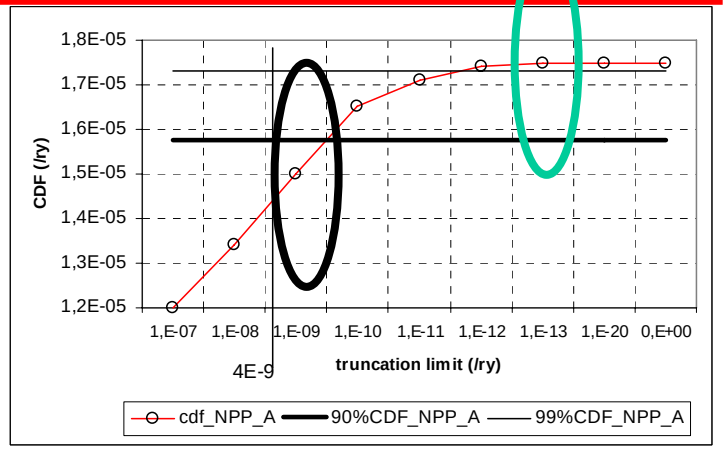
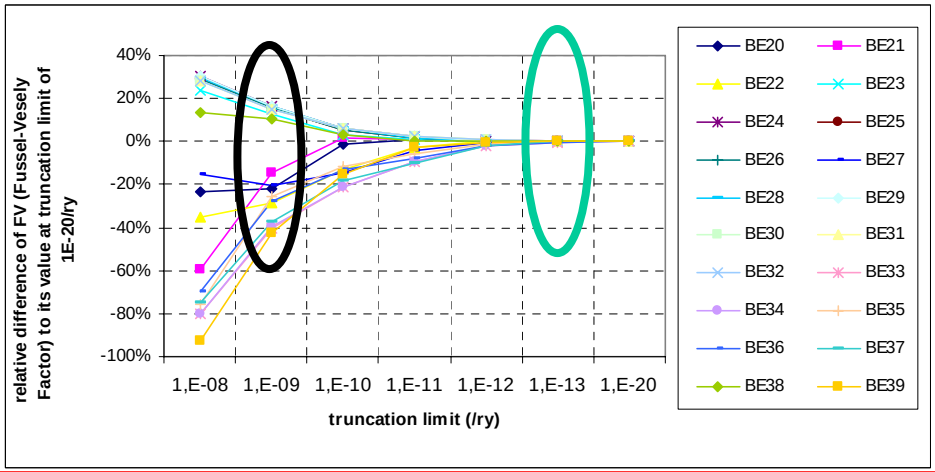
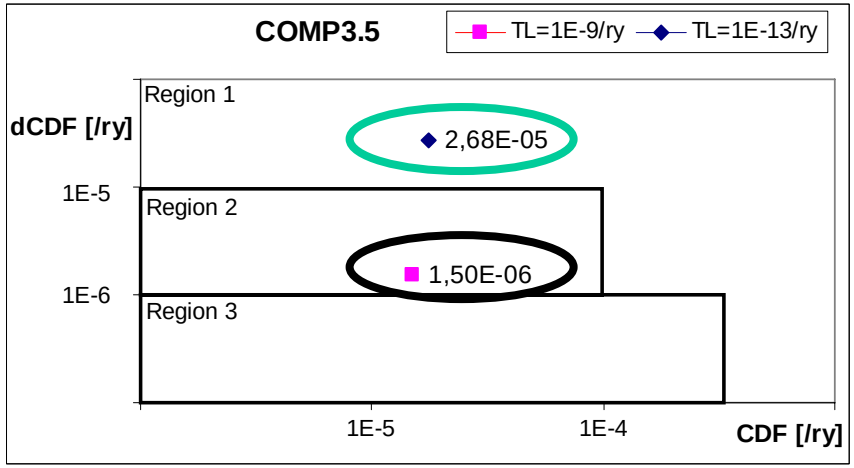
TRUNCATION (or CUT-OFF)

M. Čepin, Analysis of truncation limit in probabilistic safety assessment.
Reliab. eng. syst. saf., 2005, vol. 87, pp. 395-403.

Improper selection of a truncation limit may cause ambiguities at risk informed decision making. A method for setting up the truncation limit was established (Čepin, RESS, 2005).







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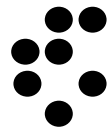
SPECIFIC CONCLUSIONS

Methods for determination of dependency between human failure events differ mostly in definition of parameters, which impact the dependency, in their application and in the determination of dependency level, which applies to a specific set of parameters. All those distinctions are subjective. This subjectivism can lead to a difference of several orders of magnitude in the results of HRA and in the PSA, which includes HRA. This means significant differences in all PSA results and their applications, e.g.:

- identification of key human failure events, which is an input for prioritisation of simulator training,
- calculation of core damage frequency and its sensitivity to changes, which is an input for risk-informed decision-making,
- identification of different key tasks within human failure event in order to identify the key parameters from HRA database.

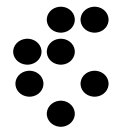
What can be and must be done is preparation of more detailed guidelines for HRA application highlighted with many practical examples for all possible situations .



GENERAL CONCLUSIONS

HRA including dependency is a very time consuming task.
HEPs are very sensitive to selection of a dependency method.
The identification and evaluation of post-initiator HFE is much more difficult as it is for pre-initiators due to larger number of post-initiators.

It is difficult to consider HEP including dependency and at the same time avoid conservatism and keep the modeling simple:
-a HFE may be dependent on some HFEs and may not be dependent on some others,
-Some event may be differently dependent on some HFEs than on other HFEs



As far as the laws of mathematics refer to reality, they are not certain;
and as far as they are certain, they do not refer to reality. **Albert Einstein**

THANK YOU FOR YOUR ATTENTION

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