Use of PRA in Risk-Informed Classification of Piping Segments of Loviisa NPP

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Loviisa VVER-440, Finland

- Two VVER-440 Type 213 units operated by Fortum Power and Heat
- Loviisa 1 commissioned in 1977
- Loviisa 2 commissioned in 1980
- Plant design based on the former Soviet concept but
- Adapted to Finnish conditions and US safety requirements
- Power upgrade up to 510 MW in 1996-1997
- New operation licences until 2027 and 2030 (Unit 1 and Unit 2), respectively

Background

- The 10 years' period ASME ISI-programme ended 2007
- RI-ISI required by the new regulatory guide in Finland
- Principles for drawing up new RI-ISI-programme were determined during the Summer-Autumn 2005
- Nuclear Authority (STUK) accepted the Plan with some modifications in August 2006
- Starting basis was the EPRI method as described in ASME XI, Appendix R, Method B
  - Applied for the whole plant
  - Relies on the existing full-scope PRA

Main principles

- All systems of the plant are covered
- Risk evaluations based on full scope PRA covering
  - internal and external events
  - Full, low and non-power states
- Consequences evaluated and classified according to Conditional Core Damage Probability (CCDP) and Large Early Release Probability (CLERP)
- Piping failure possibility is evaluated by expert judgement on qualitative basis
- Reviewed in independent panel meetings
- Only piping

Risk classification

CCDP from PSA

Qualitative assessment by group of experts

		Consequence Category			
		N.A.	Low $10^{-6} \leq$CCDP $<10^{-5}$	Medium $10^{-5} \leq$CCDP $<10^{-4}$	High CCDP $\geq 10^{-4}$
Failure Potential Category	High	Risk Category 7	Risk Category 5	Risk Category 3	Risk Category 1
	Medium	Risk Category 7	Risk Category 6	Risk Category 5	Risk Category 2
	Low	Risk Category 7	Risk Category 7	Risk Category 6	Risk Category 4

Screening limit CCDP < 10^{-6}
and CLERP < 10^{-7}

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Identification of systems

All systems:

- Safety systems
  - emergency cooling, residual heat removal, extinguishing systems, ...
  - ventilation, seal water, ...
- Operating systems
  - primary circuit, steam lines, turbine, generatori, ...
  - turbine lubrication, stator cooling, ...
- Others
  - water pipes, sewer pipes, compressed air, ...

All media

- Water,steam
- Nitrogen, air, Hydrogen
- Oil
- Chemicals
- Empty pipes

Consequence evaluation (worst possible leakage)

- Initiating event
  - CCDP/CLERP contributions from all Plant Operating States
- System failure, unavailability
  - CCDP = 1 – exp(-CCDF·t)
  - t = exposure time that the pipe failure or its consequences can exist
    - 24 h if immediately detected
    - Half of the test, maintenance or inspection interval
    - 25 years if detected only in an accident
  - Correspondingly for CLERP
- CCDP/CCDF and CLERP/CLERF for > 6000 events and 15 POSs

Consequence category

Consequence category		Level 1	Level 2
0		<1E-6	<1E-7
3		>1E-6	>1E-7
2		>1E-5	>1E-6
1	1	>1E-4	>1E-5
	1+	>1E-3	>1E-4
	1++	>1E-2	>1E-3
	1+++	>1E-1	>1E-2

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Scope

Lev 1	Lev 2	
<1E-6	<1E-7	0
>1E-6	>1E-7	3
>1E-5	>1E-6	2
>1E-4	>1E-5	1
>1E-3	>1E-4	1+
>1E-2	>1E-3	1++
>1E-1	>1E-2	1+++

RL	Feed water	1+++
RA	Steam lines	1++
RY	SG blow down	1++
TH	LPSI	1++
UJ	Fire water	1++
YA	Primary circuit	1++
YB	Steam generators	1++
YP	Pressurizer	1++
RR	RHR	1+
TC	Coolant purification	1+
TG	fuel pool cooling	1+
TJ	HPSI	1+
TP	Nitrogen supply	1+
TQ	Spray	1+
TV	Sampling	1+
TY	Drainages and vents	1+
VC	Main sea water	1+
VF	Service water	1+
YD	PCP	1+
RC	Turbine by-pass	1
RQ	Aux. steam	1
TB	Chem. supply	1
TF	Intermediate cooling	1
TM	Pool water treatment	1
UP	Diesel fuel tank	1
YC	Reactor vessel	1
SC	Lubrication	2
SE	Turbine governor	2
ST	Hydrogen	2
SU	Sealing oil	2
UV	Air conditioning	2
UX	CO_2	2
XU	External spray	2
EY	Diesel generators	3
RV	Deionate supply	3
SA	Turbine casing	3
TD	Boron water treatment	3
TE	Coolant let-down	3
TK	Normal make-up	3
TN	Supply system	3
TU	Decontamination	3
TZ	Special sewerage	3
VU	XU cooling	3
XL	Ice condencer	3
KT	Gas turbine	0
RB	Super heating	0
RD	HP bleeding points	0
RE	Main condensate purif.	0
RF	Sealing water for MFW	0
RH	LP bleeding points	0
RM	Main condensate	0
RN	Auxiliary condensate	0
RT	Pipe drains	0
RU	Drain and return system	0
SB	Turbine bearings	0
SD	Condenser	0
SG	Gland steam	0
SH	Turbine drain system	0
SS	Stator water cooling	0
TL	Ventilation	0
TR	Sewage water treatment	0
TS	Radioactive gaseous waste	0
TT	Solid active waste	0
TW	Liquid active waste	0
UA	Demineralisation plant	0
UC	Other water treatment	0
UH	Dosing equipment	0
UK	Drinking water	0
UL	Sewerage	0
US	Compressed air	0
UT	Other gas supplies	0
UU	Aux. boiler plant	0
UW	Venting and heating	0
VA	Sea water treatment	0
VE	Condenser purification	0
VG	Conventional interm. cooling	0
XM	Ice condenser cooling	0
XN	Circulating air fans	0
XP	Ice manufacturing	0
XW	Hydrogen control	0
YF	Thermal shield	0
YZ	Plant protection	0

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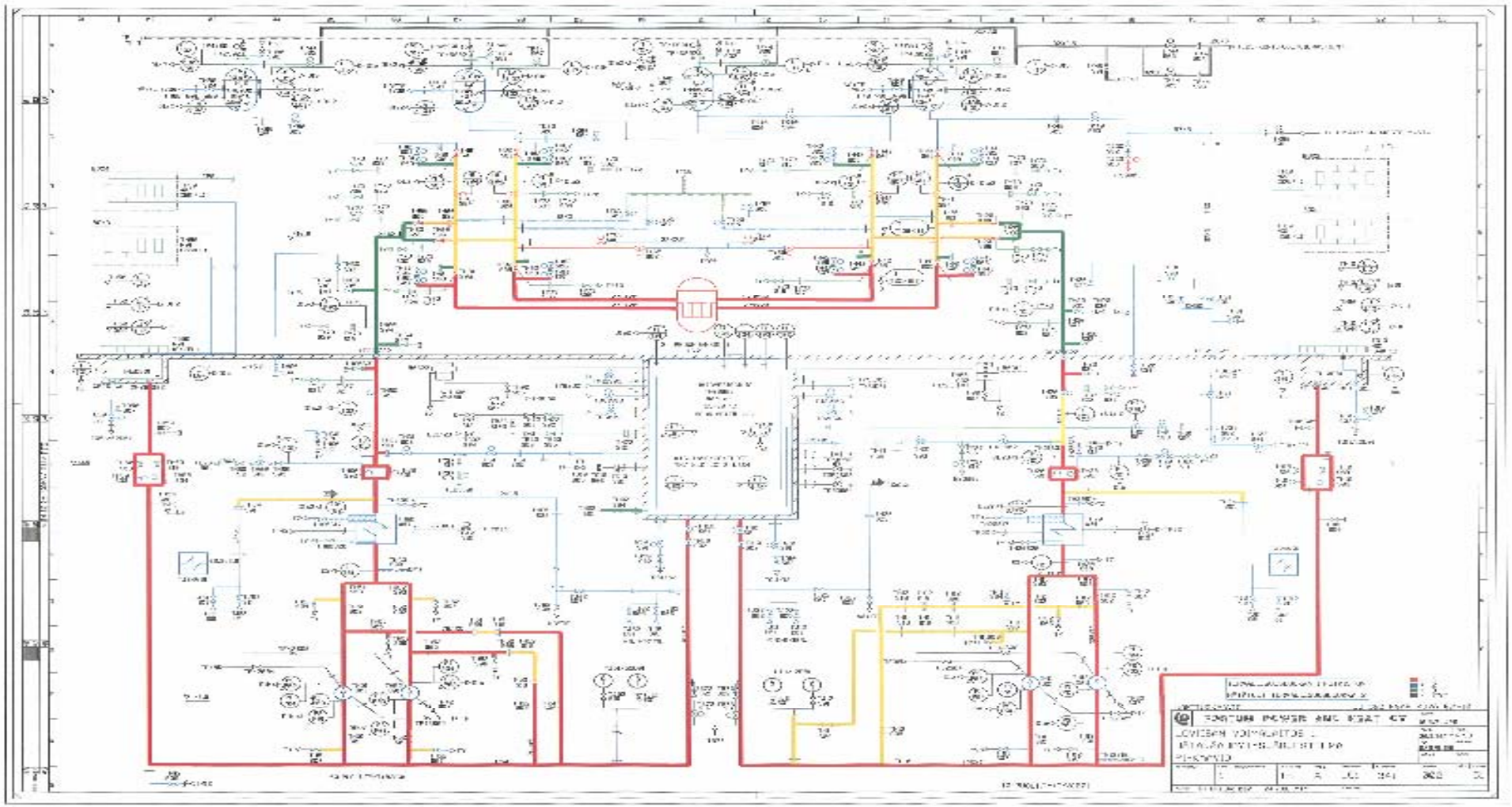
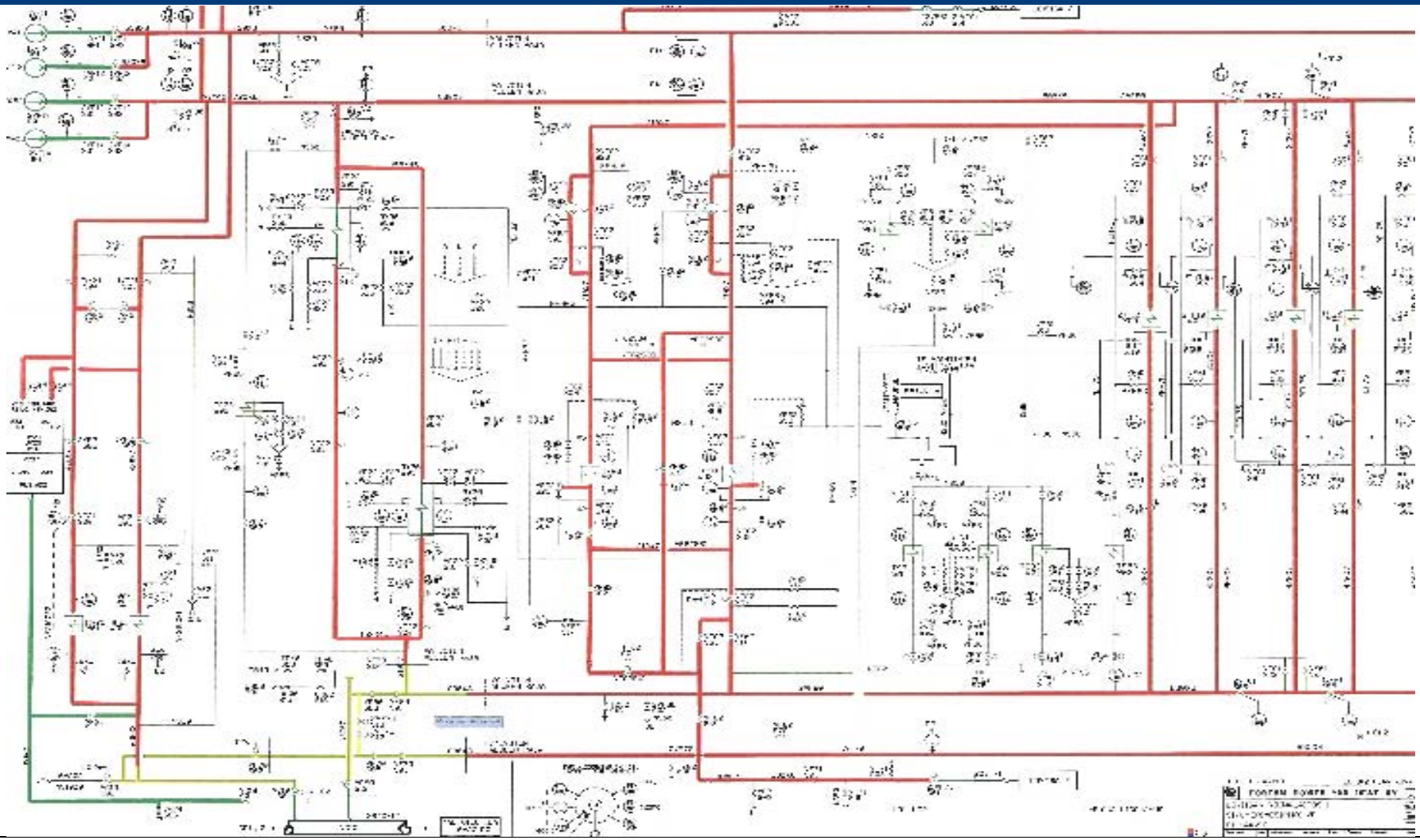
Emergency core cooling (LPSI)



Service water system



Risk categories of the consequence category High

System	Risk	System	Risk
Pressurizing	**1**	Diesel generator	4
Feed water	**1**	Residual heat removal	4
Main steam	**2**	Supply of chemicals	4
Turbine by-pass	2	Fuel pond cooling	4
Auxiliary steam	2	**Low pressure safety injection**	**4**
Steam generators blow-down	2	Pond water treatment	4
Coolant purification	**2**	Supply systems (nitrogen, gas, air)	4
High pressure safety injection	**2**	Containment spray	4
Circulating water	2	Sampling (reactor building)	4
Service water	2	**Drainages and vents**	**4**
Primary circuit	**2**	Diesel generator fuel oil	4
Steam generator pipelines	**2**	Containment external spray	4
Primary circulating pumps	**2**	Reactor vessel, measurement	4
Fire fighting water	2		

Systems in bold blue font belong to the old ASME ISI program.

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Risk categories of the cons. cat. Medium and Low

System with Medium consequence	Risk	System with Low consequence	Risk
Turbine lubrication	5	Secondary makeup	7
Turbine governor and protection	5	Turbine casing	7
Generator hydrogen	5	Boron water treatment	7
Turbine sealing oil	5	Prepurification of coolant drainage	7
Air conditioning	6	**Primary makeup**	**7**
Ice condenser	6	Primary supply (liquid, steam)	7
Fire and gas protection	6	Plant and equipment decontamination	7
		Liquid active waste storage	7
		Special sewerage	7
		Cooling of the containment external spray	7

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RI-ISI brought several new features

- Inspection locations of the primary circuit piping are reduced but new systems are included (radiation exposure will be reduced)
- Small diameter primary piping (new methods needed)
- Consequence differences of redundant safety systems
- Exceptionally high consequence targets need special attention
- Empty and pressure-free piping need reasonable new methods

Other benefits

- Extensive documentation in electronic form (old tehcnical drawings)
- Co-operation between experts of different organizations and professional areas
- Total risk will decrease

Summary of the features of this approach

- All systems containing water, gases, chemicals and empty,…
- All operating modes (15) were taken into account when quantifying CCDP and CLERP values
- Shutdown risks were important in many consequence evaluations
- Exposure times were carefully estimated
- High consequence categories can be caused by pipe breaks that lead to basic events only – usually they come from initiating events
- Piping selection by screening on the basis of CCDP and CLERP
- Indication of exceptionally high consequence values
- Redundant identical pipelines can have different consequence categories (e.g. because of layout)