International Conference on Non-Electric Applications of Nuclear Power: Seawater Desalination, Hydrogen Production and other Industrial Applications

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Overview of the Safety Aspects of Nuclear Desalination Coupling

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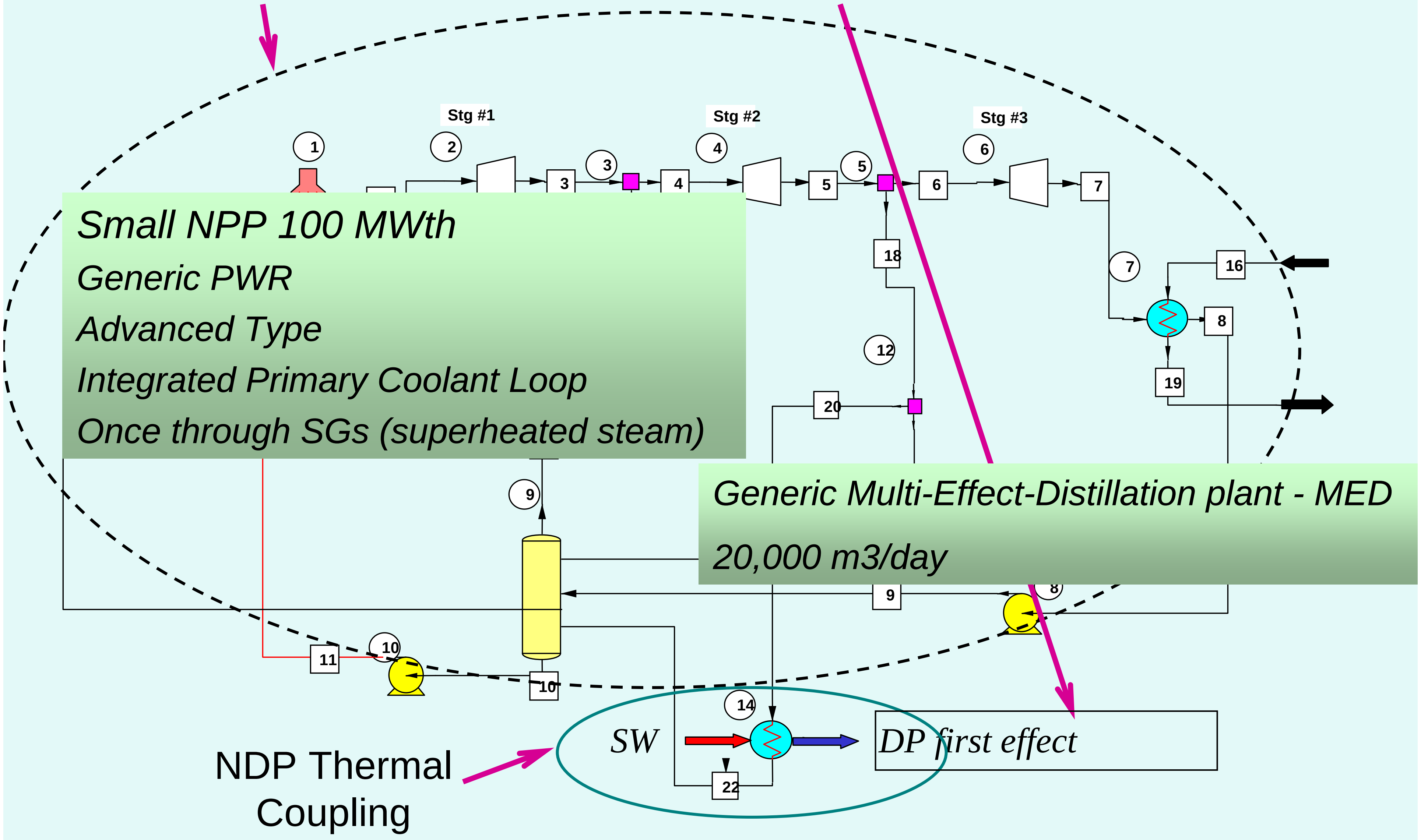
Introduction

Overview of the Safety Aspects of ND thermal coupling includes:

- *Nuclear safety approach*
- *Generic issues that should be included in the NDP SAR*
- *Conceptual design of Coupling systems (two different ESFs)*

NPP + DP = NDP


Stg #1
Stg #2
Stg #3
1
2
3
4
5
6
7
8
9
10
11
12
14
16
18
19
20
22
Small NPP 100 MWth
Generic PWR
Advanced Type
Integrated Primary Coolant Loop
Once through SGs (superheated steam)
Generic Multi-Effect-Distillation plant - MED
20,000 m3/day
SW
DP first effect
NDP Thermal Coupling

Safety Approach

Safety objective of NDP coupling

- ❑ No adverse effect on the safety of the NPP ✓
- ❑ To ensure that no hazards (different nature/higher probability) than those stated in the NPP SAR arise

The only relevant **safety function** related to a coupling system is the confinement of radioactive material (reactivity and cooling are not an issue)

The potentially radioactive source is not necessarily the reactor core but the BoP water

Safety Objective derives in **General Safety Design Requirements**

 # 1: Provision of barriers between potentially radioactive material and PW

 # 2: Provision of features preventing radioactive material from reaching PW in case of failure sequence

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Commonly used terms

✓ ***PIE:*** Events giving rise to failures or a sequence of failures leading to accidental conditions

✓ ***Accidental Sequence:*** the evolution of the plant starting from a PIE and according to a possible sequence of failures

✓ ***Envelope Safety Case:*** the accidental sequence with the most severe consequences

✓ ***Critical Group:*** the group of people that has the higher probability of being exposed to the effluents of the NP

✓ ***Defence-in-Depth concept:*** successive barriers providing graded (envelope) protection against transients. The levels of defence in depth are:

a) Prevention of deviations from normal operation/ failures;

b) Control of such deviations/failures to prevent AOO to reach accident conditions;

c) Control of the consequences of the resulting accident conditions;

d) Control of severe conditions including prevention and mitigation of the consequences;

e) Mitigation of radiological consequences

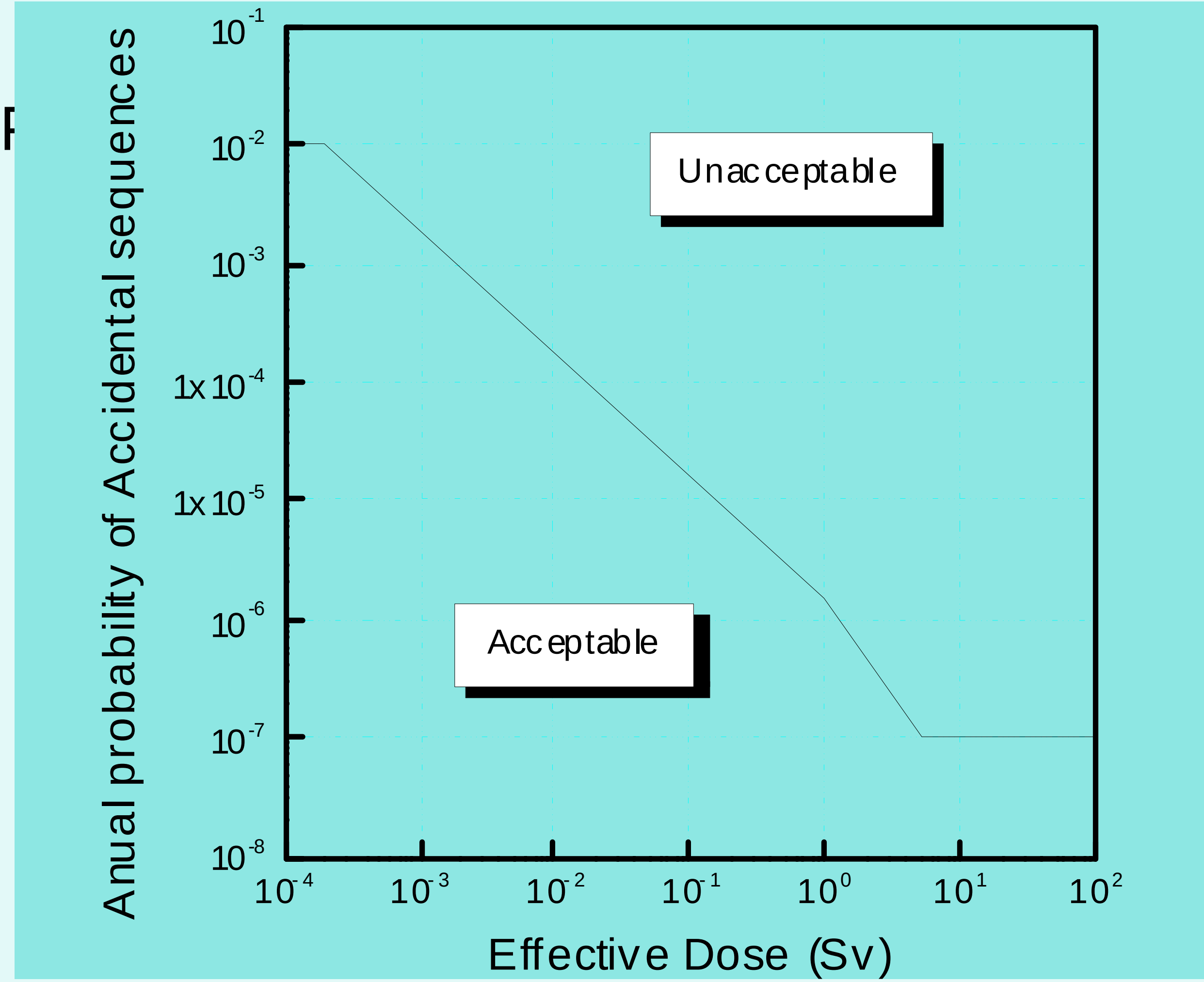
Safety Approach - Proposed Structure of SAR

- NPP-SAR based on a deterministic safety approach

- DP coupling to a N

Up-date style safety

Probabilistic approach



Safety Approach - Proposed Structure of SAR

DP ➡ Implies a major modification to the design

DP-SAR

- an appendix, self-standing document
- submission does not imply a NPP-SAR revision

"NRC Standard format and content of SAR for NPP"

Adopted as a guide

Only to provide a uniform **format** for presenting the information

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Specific Contents of the SAR for a NDP

Chapter 1: Introduction and General Description of the Facility

Chapter 2: Site characteristics

"Consumers group" *= or ≠* *"Critical group"*

Chapter 3: Design of Structures, Components, Equipment and Systems

Chapter 4: Reactor *Not applicable for the DP SAR*

Chapter 5: Desalination System and Connected Systems

Chapter 6: Engineered Safety Features

Chapter 7: Instrumentation & Control

Chapter 8: Electric Power

Chapter 9: Auxiliary Systems

Chapter 10: Steam and Power Conversion System

Chapter 11: Radioactive Waste Management *No radioactive waste produced*

Specific Contents of the SAR for a NDP

Chapter 12: Radiation Protection

Changes in radioactive background of seawater

Intake limiting values under NPP accident conditions

Chapter 13: Conduct of Operations

Chapter 14: Initial Test Program

Chapter 15: Safety Analysis

A list of PIE presented

Safety cases identified and assesed

Chapter 16: Technical Specifications

Limiting Conditions for Safe Operation

Chapter 17: Quality Assurance

Additional chapters according to SAR format index

The best way to provide a smooth licensing processing **?** *Include self-standing chapters*

Chapter (*): Safety Objectives and Engineering Design Requirements

- ✓ *Description of Safety Objectives*
- ✓ *Derivation of Safety Design Requirements*
- ✓ *Development into specific Engineered Safety Features*
- ✓ *Defence-in-Depth philosofy*

Chapter (*): Environmental Assessment — *If not already done, include it here*

Chapter (*): Decommissioning — *Design provisions for an easy DP decommissioning task*

Conceptual Safety Analysis of the Safety Case

Construction of the PIE list

Defense-in-Depth barriers

Level	*Main characteristics*	*Safety features*
✓ Main HX breaks ✓ SG fails ✓ Nuclear fuel matrix/cladding fail		water form BoP into DP primary coolant enters the BoP fission products to primary coolant
Highly unlikely	*NPP detection means*	*Severe contamination*
✓ Main HX leaks		water form BoP into DP
Quite likely		*Weak contamination within the DP*

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Summary

translated into

Safety objective of NDP coupling → **GSDR**

reflected

Conceptual design of a Coupling System = Confinement of radioactive material

Following defence-in-depth principles

ESF

Potable Water Monitoring

Pressure Reversal in HX

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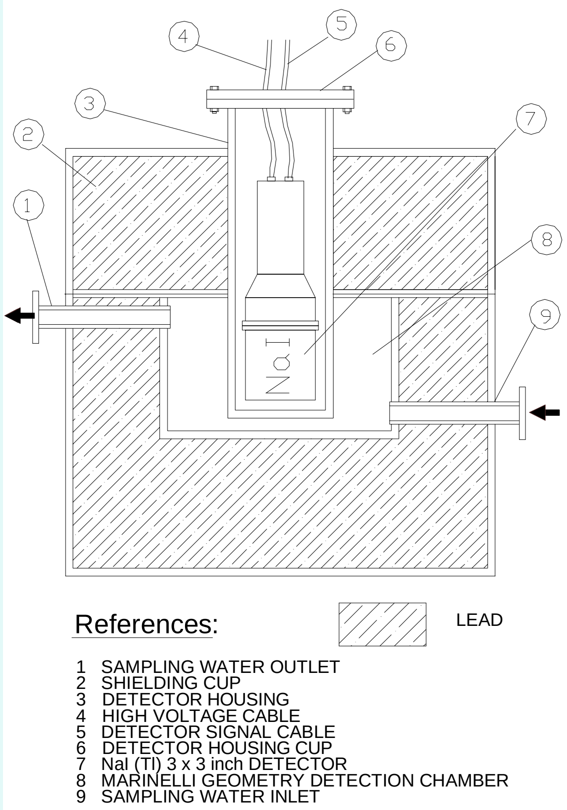
INVAP contributions and findings on PWM

Design key issue: the measuring time needed to reliably detect radioactive levels below acceptable limit

Measuring γ in arrangements of Marinelli devices

Expertise handling statistics (sensitivity, precision, confidence, design margins), admissible spurious trip frequency, I&C and process design

The allowable activity for PW (e.g. WHO) and data on the available sensors one gets the minimal Measuring Time for the sampling and then the hold up requirement (tank volume)

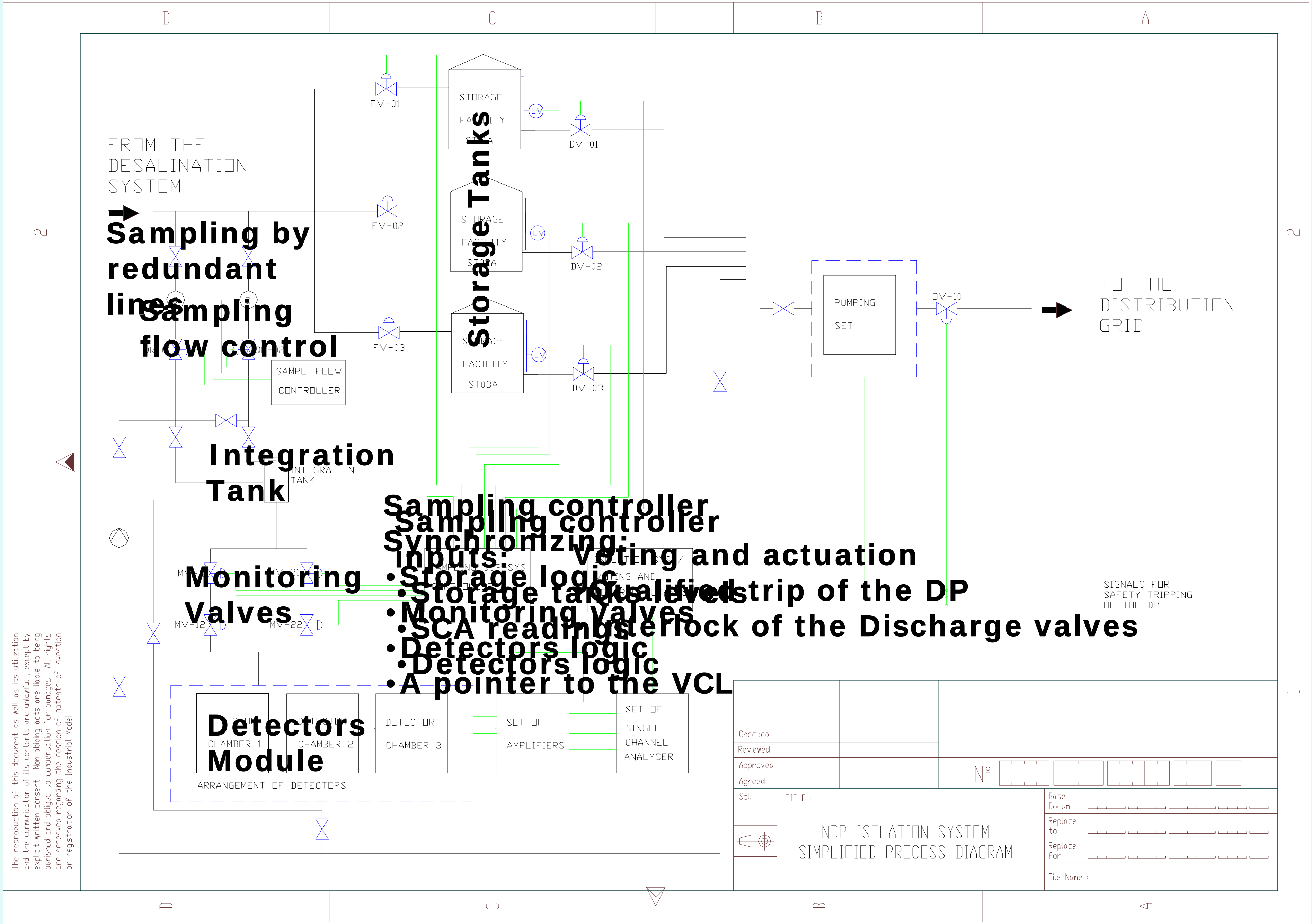


Number of tanks: N = or > 3

Hold-up time required ~ 60 minutes

For a typical MED DP of 20.000 m³/day, preliminary estimations of minimum scope Isolation System is ~ 800.000 U$S and the impact would be bigger for smaller plants

Typical MED unit cost (900 U$S/m³/day), 18 MU$S for the assumed DP


FROM THE DESALINATION SYSTEM
Sampling by redundant lines
Sampling flow control
SAMPL. FLOW CONTROLLER
FV-01
FV-02
FV-03
Storage Tanks
STORAGE FACILITY
STORAGE FACILITY ST02A
STORAGE FACILITY ST03A
LV
DV-01
DV-02
DV-03
PUMPING SET
DV-10
TO THE DISTRIBUTION GRID
Integration Tank
INTEGRATION TANK
Monitoring Valves
MV-21
MV-12
MV-22
Sampling controller
Synchronizing:
•Storage logic
•Monitoring valves
•Detectors logic
•A pointer to the VCL
Sampling controller
Inputs:
•Storage tanks levels
•SCA readings
•Detectors logic
Voting and actuation
•Qualified trip of the DP
•Interlock of the Discharge valves
SIGNALS FOR SAFETY TRIPPING OF THE DP
Detectors Module
CHAMBER 1
CHAMBER 2
DETECTOR CHAMBER 3
ARRANGEMENT OF DETECTORS
SET OF AMPLIFIERS
SET OF SINGLE CHANNEL ANALYSER
Checked
Reviewed
Approved
Agreed
Scl.
TITLE :
NDP ISOLATION SYSTEM
SIMPLIFIED PROCESS DIAGRAM
Nº
Base Docum.
Replace to
Replace for
File Name :
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contributions and findings on PR

Design key issue**:** BoP side pressure < DP side pressure

The coupling is performed by a pressurised clean-water Intermediate Loop (IL), joining the Main HX (with BoP) and the evaporator (with DP)

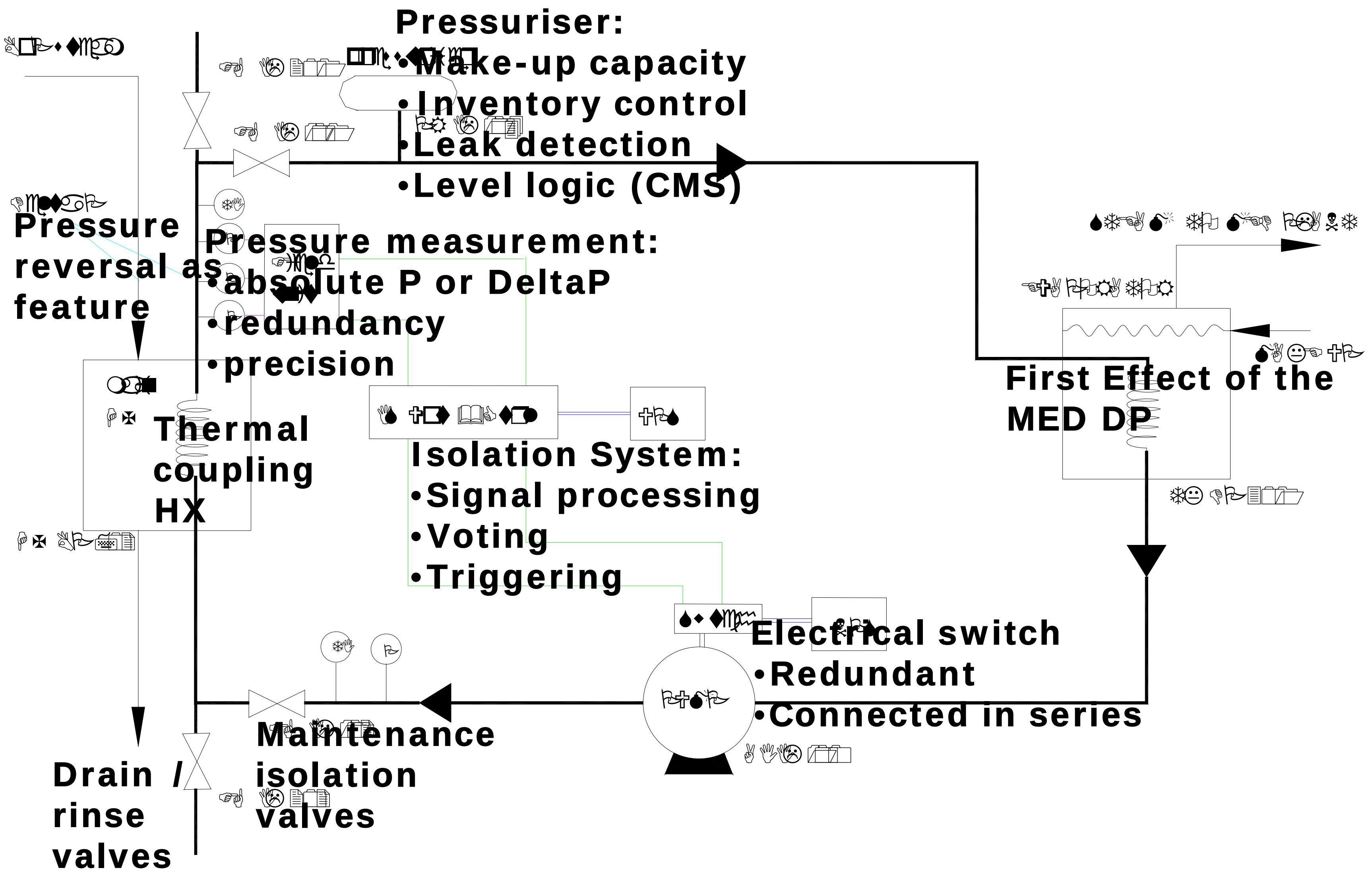
Pressure sensors monitor the ΔP between the sides of the Main HX (barrier)

Expertise handling statistics (sensitivity, precision, confidence, design margins), admissible spurious trip frequency, I&C and process design

Technology requirements for the IS are low (only of-the-shelf equipment)

For the assumed MED DP the estimation of 34.000,- U$S for the complete IS is negligible against the DP cost

The impact on the NDP Project by adding an IL itself still remains as a an open issue


Pressuriser:
•Make-up capacity
•Inventory control
•Leak detection
•Level logic (CMS)
Pressure reversal as feature
Pressure measurement:
•absolute P or DeltaP
•redundancy
•precision
Thermal coupling HX
Isolation System:
•Signal processing
•Voting
•Triggering
First Effect of the MED DP
Electrical switch
•Redundant
•Connected in series
Maintenance isolation valves
Drain / rinse valves

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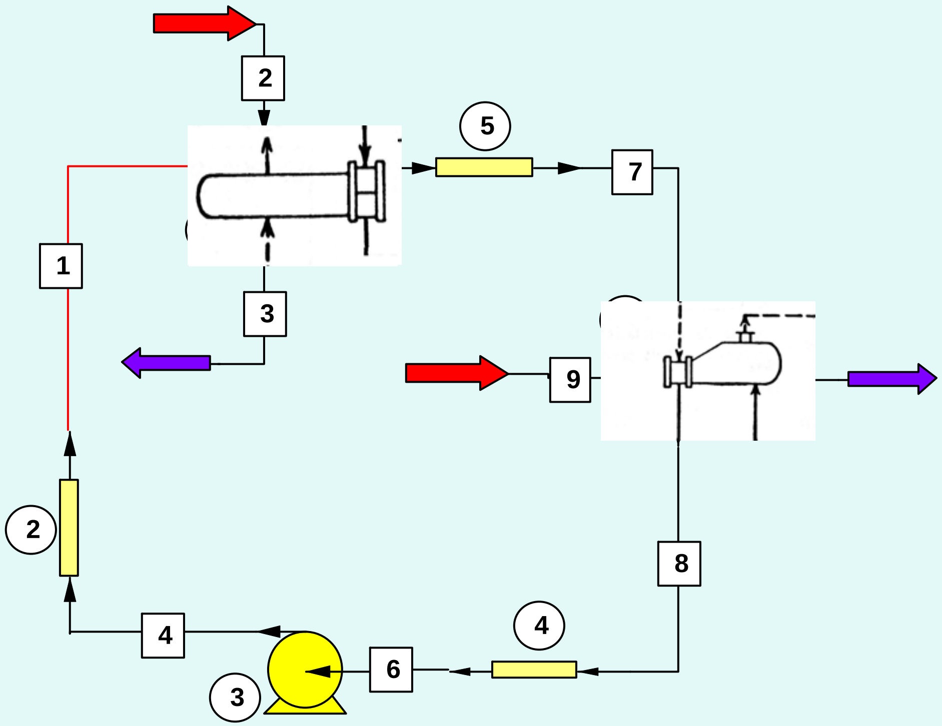
Intermediate Loop w/ Pressure Reversal

Modelling w/Chemcad



Stream #	Turb-extr-3	Steam Cond.	I-Loop-Cold-HP	I-Loop-Hot	I-Loop-Cold-LP	MED-Feed	MED-Steam
T [C]	158.9	**134.5**	134.4	151.1	134.4	130.0	**132.2**
P [bar]	6	5.96	**9.00**	8.67	8.28	2.75	**2.696**
X [-]	1	0	0	0	0	0	**1**
F [kg/h]	11500	11500	**350000**	350000	350000	11610	**11610**

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Findings

Reference case

Stream #	Turb-extr-3	Steam Cond.	I-Loop-Cold-HP	I-Loop-Hot	I-Loop-Cold-LP	MED-Feed	MED-Steam
T [C]	158.9	**134.5**	134.4	151.1	134.4	130.0	**132.2**
P [bar]	6	5.96	**9.00**	8.67	8.28	2.75	**2.696**
X [-]	1	0	0	0	0	0	**1**
F [kg/h]	11500	11500	**350000**	350000	350000	11610	**11610**

Turbine extraction at 4 bar instead of 6 bar

The use of a Hig … neral sol … hermal coupling

Reduces efficiency

Stream #	Turb-extr-3	[illegible]team Cond.	I-Loop-Cold-HP	I-Loop-Hot	I-Lo[illegible] Cold-LP	[illegible]ED-F[illegible]d	MED-Steam
T [C]	143[illegible]	133.7	138.0	141.5	138.0	13[illegible]	**129.8**
P [bar]	4	3.99	6.98	6.58	6.36	2.75	**2.68**
X [-]	1	0	0	0	0	0	**1**
F [kg/h]	11500	11500	1500000	1500000	1500000	10400	**10400**

Findings

Reference case

Stream #	Turb-extr-3	Steam Cond.	I-Loop-Cold-HP	I-Loop-Hot	I-Loop-Cold-LP	MED-Feed	MED-Steam
T [C]	158.9	**134.5**	134.4	151.1	134.4	130.0	**132.2**
P [bar]	6	5.96	**9.00**	8.67	8.28	2.75	**2.696**
X [-]	1	0	0	0	0	0	**1**
F [kg/h]	11500	11500	**350000**	350000	350000	11610	**11610**

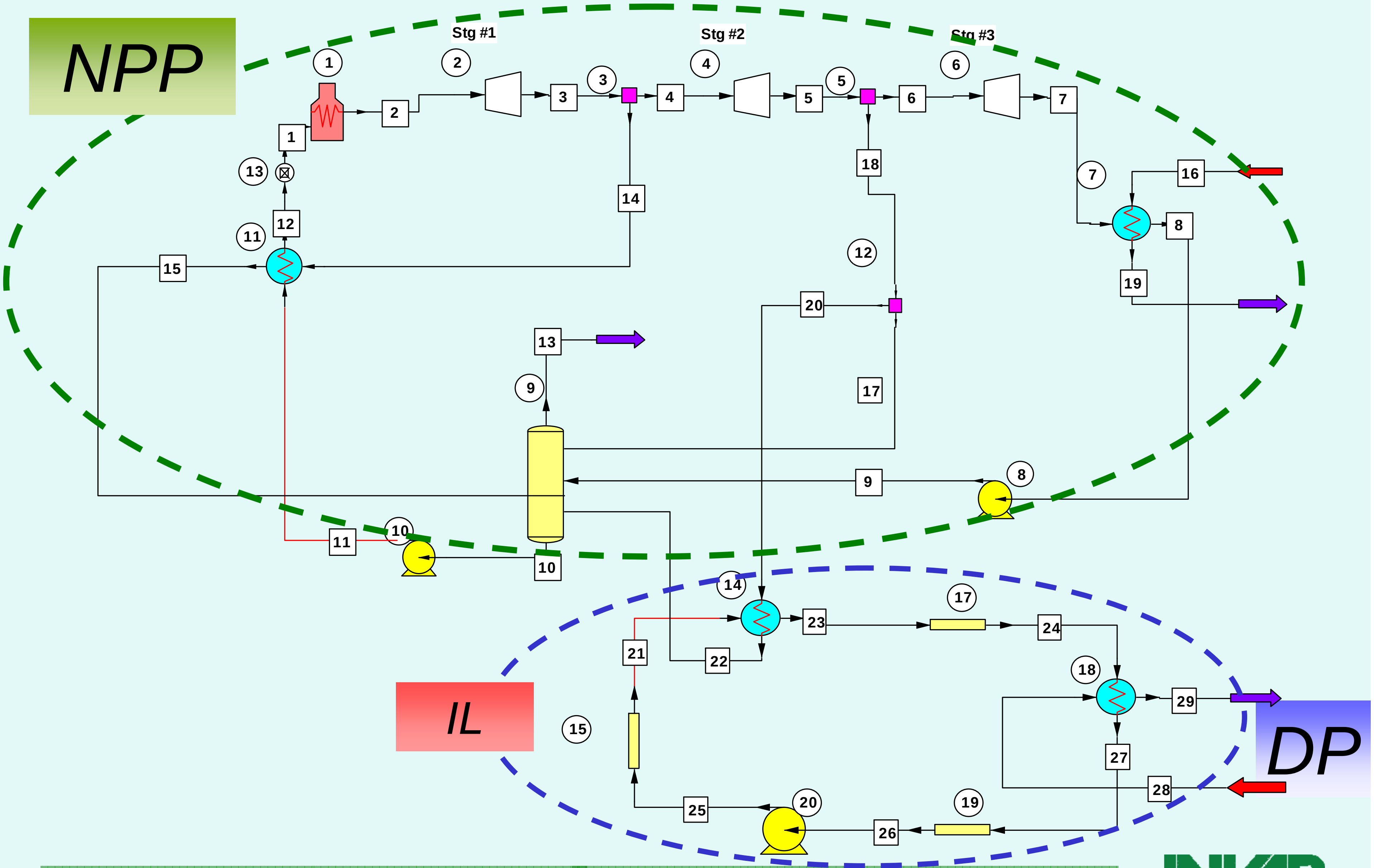
Higher pressure
> Pumping power

If t … ncrease in distance … er of magnitude

Same
efficiency

Stream #	Turb-extr-3	S… m Con…	I-Loop-Cold-HP	I-Loop-Hot	… Cold-LP	MED-Feed	MED-Steam
T [C]	158.9	134.5	134.5	151.2	134.4	[illegible]	**133.6**
P [bar]	6	5.96	**10.35**	9.0	7.57	2.7[illegible]	**2.69**
X [-]	1	0	0	0	0	0	**1**
F [kg/h]	11500	11500	350000	350000	350000	11610	**11610**

Idea of the Model



Conclusions

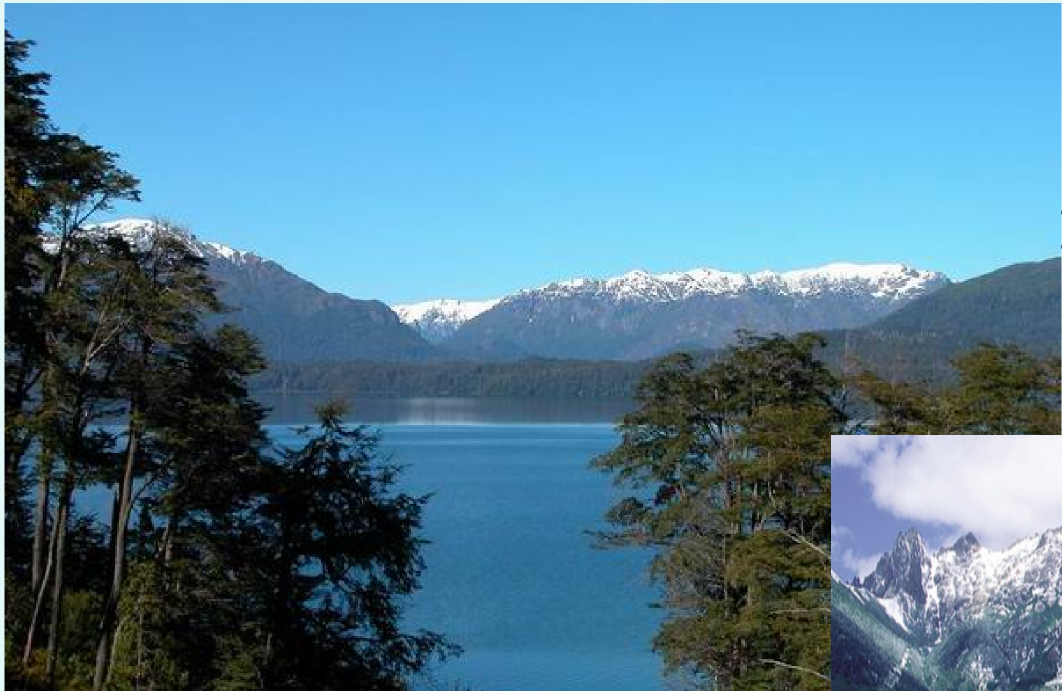
- ✓ Commonly accepted techniques used for deterministic safety analysis of NPP can be applied to NDP

- ✓ The SAR of DP can be presented as a self-standing appendix acting as a complement of the NPP SAR

- ✓ The development of ESF for the thermal coupling od NDP is an issue technically solvable within Safety Guidelines

- ✓There is not a universal IS, the optimal solution requires safety expertise

- ✓ The impact of the design solution of IS and ESF (in terms of efficiency, for example) should be considered during the first stages of a NDP when drafting user requirements



attention

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