Flexible Plant Operation and Generation Pathway Stakeholder Engagement Meeting

Thermal Energy Distribution to Industry Complex

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Project Team

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INL / BEA

- INL Technical Lead – Tyler Westover
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Thermal Power Dispatch Options

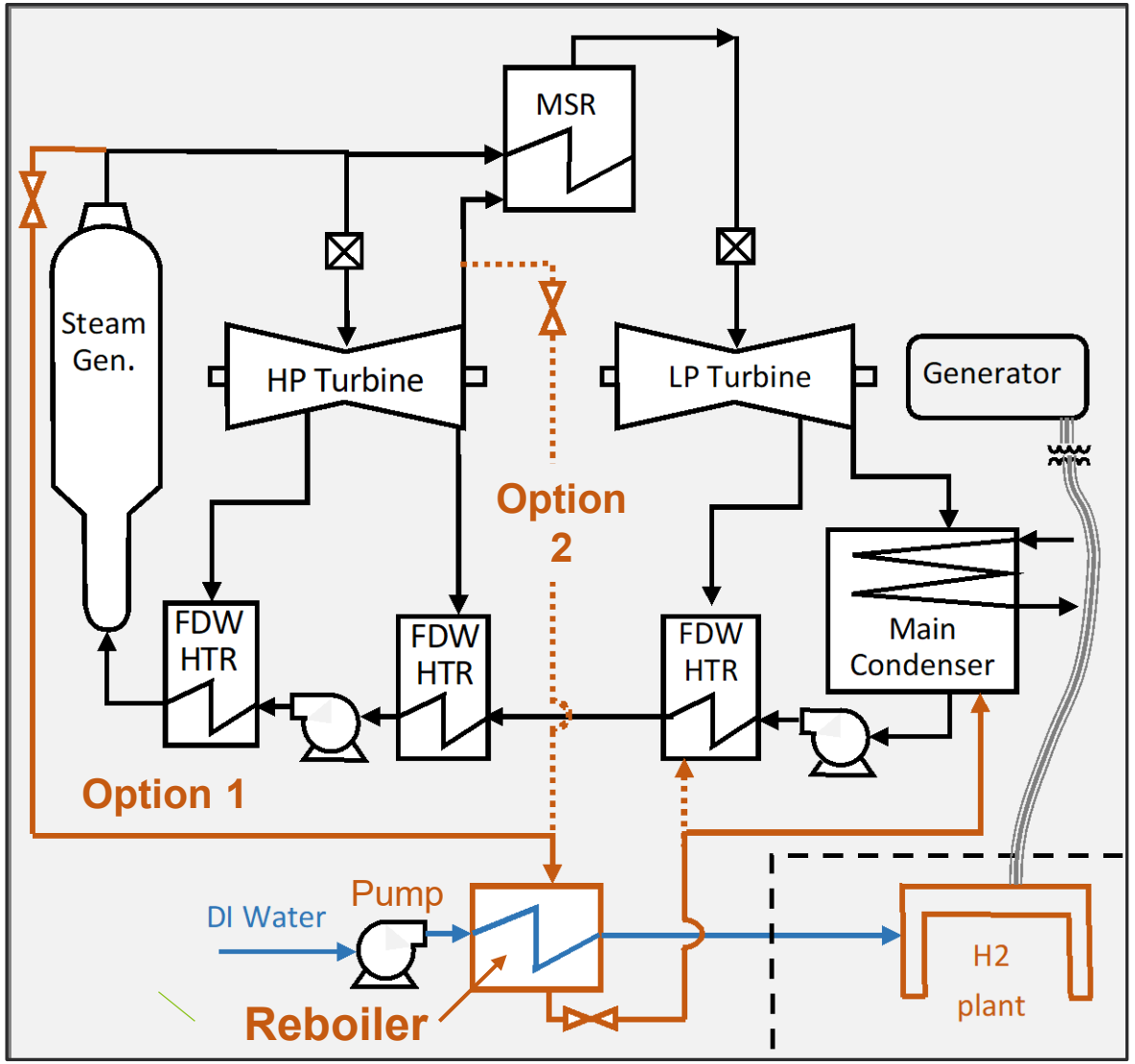
Design Option #A: Extract steam from main steam line

- For high levels of thermal power dispatch (TPD) for applications in which high temperature steam is required (>400 ºF)

Design Option #B: Extract steam downstream from high pressure (HP) turbine

- For lower levels of thermal power extraction or for applications in which low temperature steam is sufficient (<360 ºF)

- Both options send steam to a reboiler that condenses secondary steam and generates tertiary steam for dispatch
- Secondary condensate is returned to main condenser

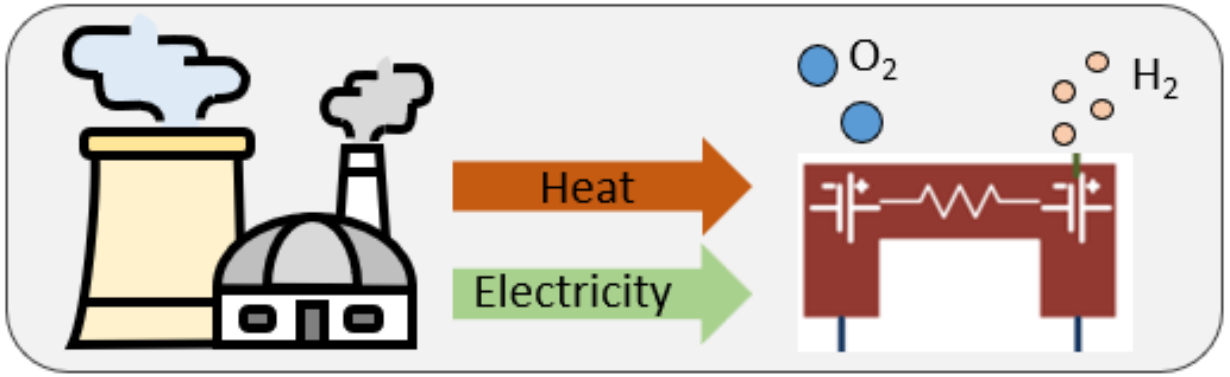


Simplified diagram of PWR/SOEC plant thermal power coupling options

Nuclear Thermal Power Dispatch (TPD) Studies

- **Completed**
  - Integrated 4-loop PWR* – 100 MW_{DC} H_2 facility
  - Integrated 4-loop PWR – 500 MW_{DC} H_2 facility
  - 30% TPD from 4-loop PWR (~1,100 MW_t)
  - 50% TPD from 4-loop PWR (~1,800 MW_t)
  - 70% TPD from 4-loop PWR (2,550 MW_t)
  - 500 MW_{DC} hydrogen facility coupled to PWR
  - Integrated 4-loop PWR – 500 MW_{DC} H_2 facility
  - Integrated BWR* – 500 MW_{DC} hydrogen facility

- **Participant Roles**
  - INL: (1) Develop the statement of work, and (2) complete PRA
  - S&L: complete preconceptual design to commercial standards
  - Westinghouse: complete the design basis for control system implementation



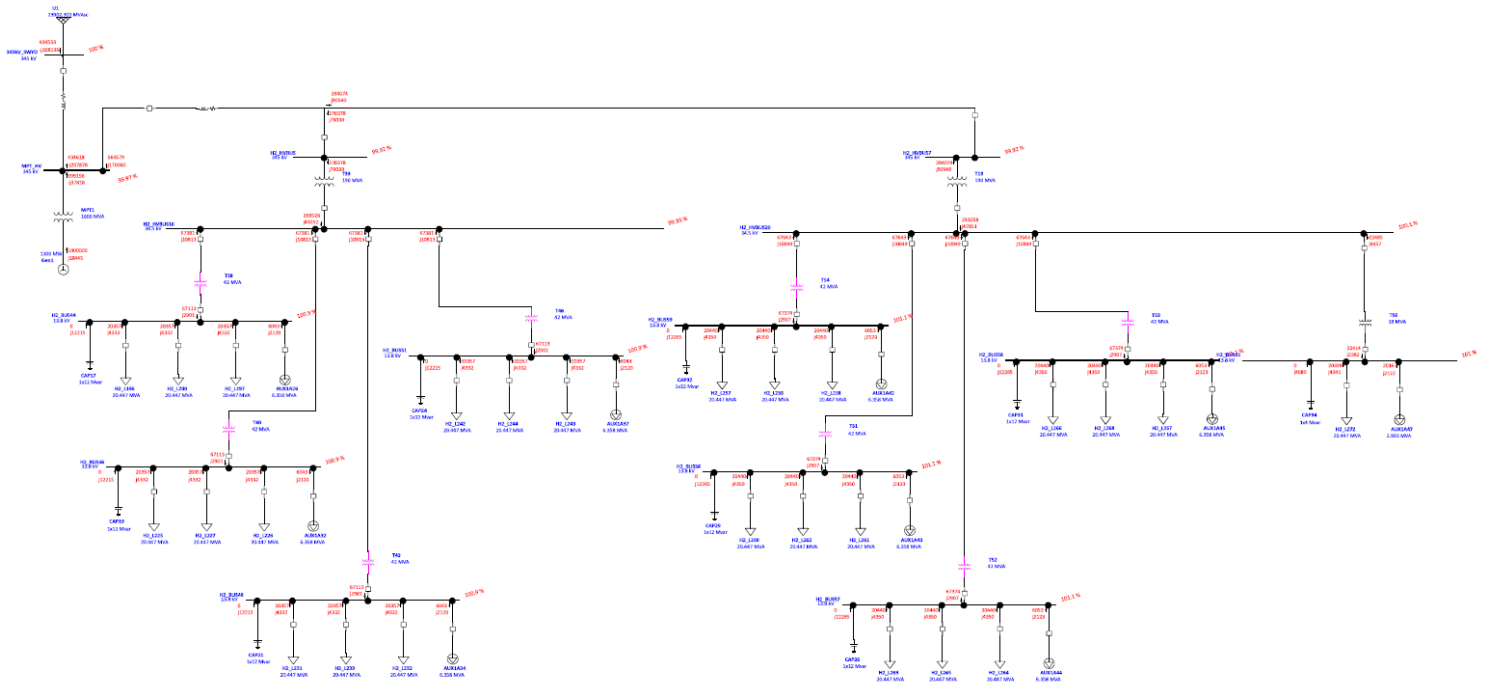
*PWR: pressurized water reactor
*BWR: boiling water reactor

S&L Pre-Conceptual Plant Designs

- **Conclusions**
  - Electrical Extraction
    - Full Generator Output viable without any plant instability issues

PSCAD - Electrical Transient Analysis

ETAP - Electrical Power Flow & Short Circuit Analysis



High-level design basis for controls for TPD Operations

1. Identify the control system considerations to be implemented in the plant
   - Allows end users to determine whether existing analog instrumentation & controls (I&C) can be used or if they need a digital I&C system
2. Identify the devices/components to be controlled and the impacts to existing control systems
3. Identify operational considerations for how operators will enable the dispatch of steam to the hydrogen generation “island”
4. Design basis includes descriptions of control system functions, interlocks, and permissives, interfaces, indications, alarms, and annunciators.

New interactions for control system

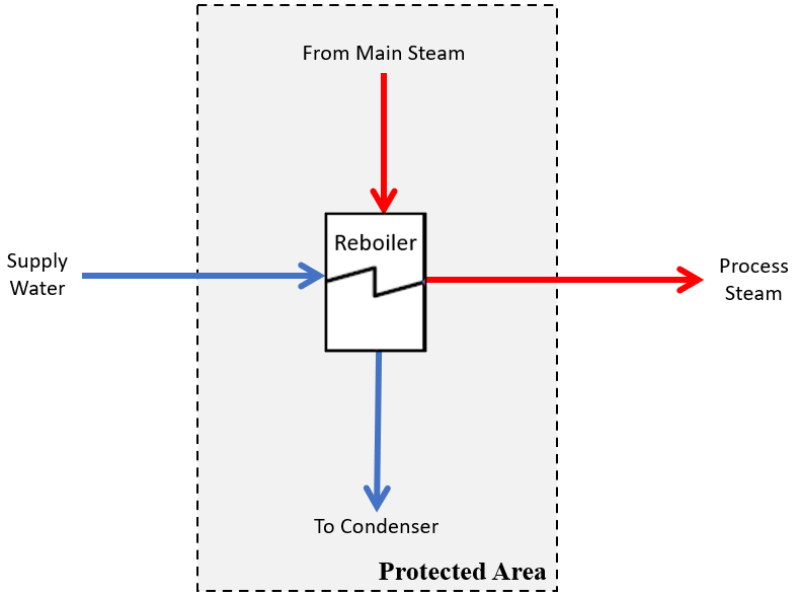
(partial list - similar for all TPD connections)

- Steam-extraction flow control valve (FCV)
- Steam-extraction FCV, interlock solenoid
- Steam-extraction flow transmitter
- Reboiler level-control valve
- Reboiler level-control valve, interlock solenoid
- Reboiler level transmitter
- Drain receiver level-control valve
- Drain receiver level-control valve, interlock solenoid
- Drain receiver level transmitter
- Reboiler outlet-pressure transmitter
- Reboiler feed-pump breaker
- Industrial plant breaker
- Industrial plant power meter

S&L 30% & 50% TPD

Thermal Analysis

- Extracted steam is condensed and subcooled before returning to the power cycle

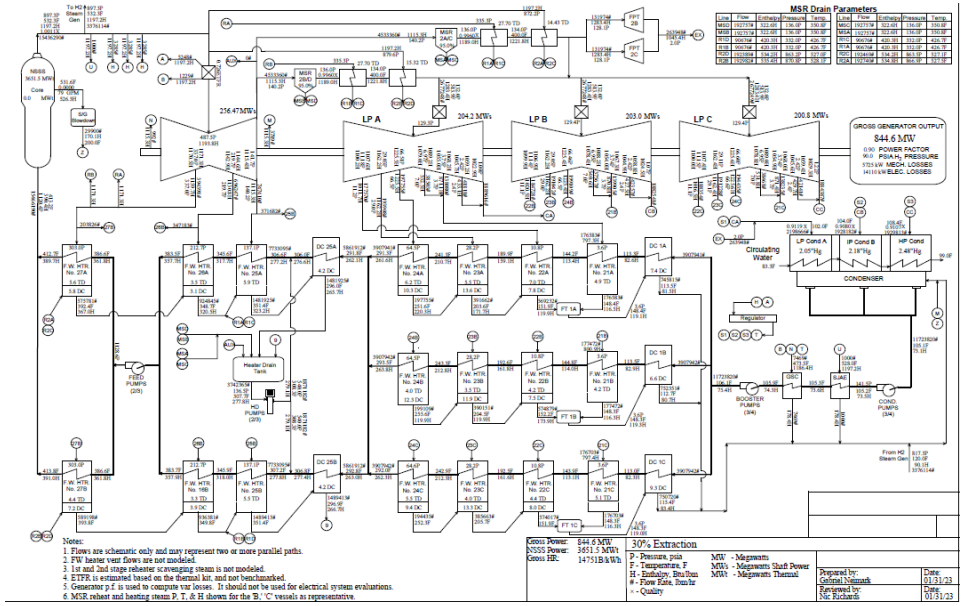


PEPSE – Thermal Extraction Analysis

Transient Analysis

- Multiple scenarios reviewed
  - Start-up
  - Shut down
  - Unit trip

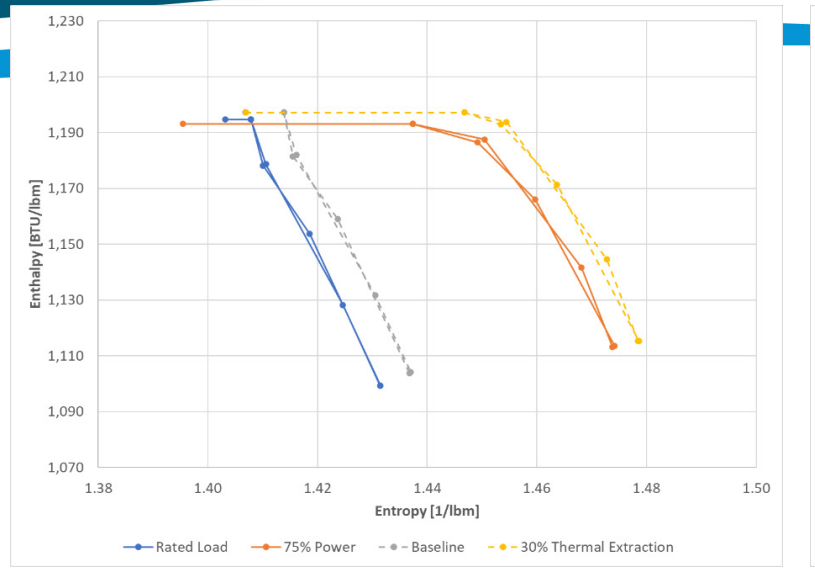
30% & 50% TPD Operation is within NPP Control System Capacity

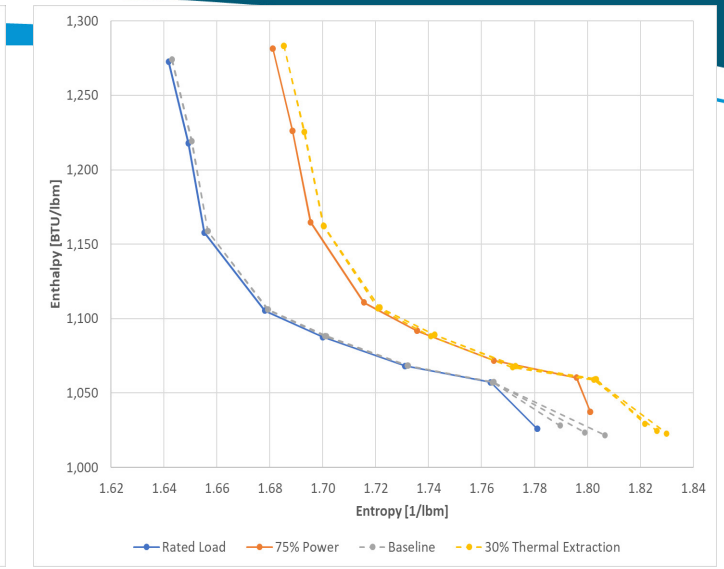


S&L 30% & 50% TPD

Major Equipment Reviewed

- ✓ High Pressure Turbines (HPTs)
- ✓ Low Pressure Turbines (LPTs)
- ✓ Condensers
- ✓ Pumps
- ✓ Moisture Separator Reheaters (MSRs)
- ✓ Feedwater Heaters (FWHs)
- ✓ Extraction Steam
- ✓ Feedwater Heater Drains
- ✓ MSR Drains





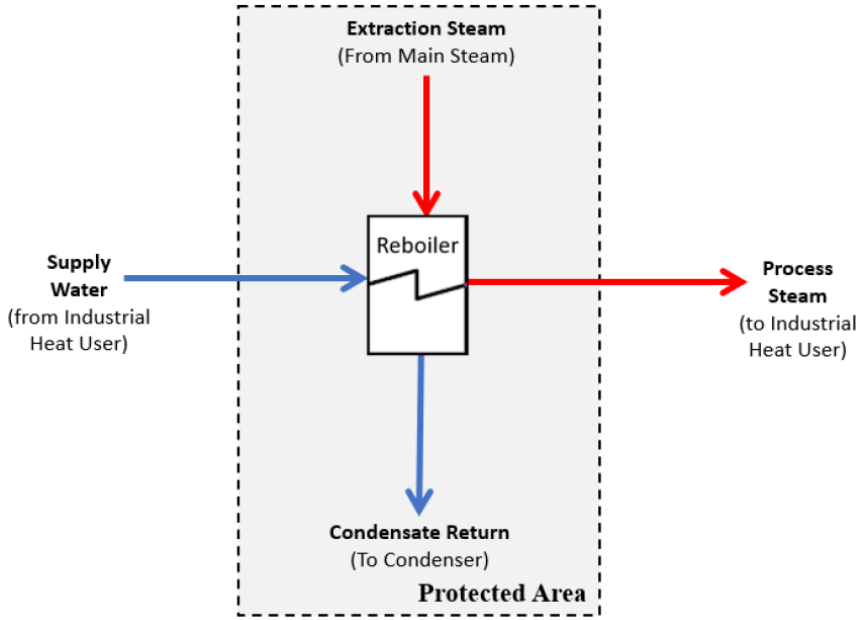
For 30% TPD, analysis shows HPT and LPT close to existing NPP 75% Power Case

Conclusions

- Safe Operation
- No Major Equipment Replacements
- Specific Plant Components may need Minor Upgrades and Maintenance

S&L 50% TPD

- Electrical Output ↓ 52%
- Main Steam Flow ↓ 38%
- **Final feedwater temperature drops 52°F**
- **Pressures in MSR/turbines drop 45%**



Description	Units	0%	50%	Δ (50%)
Generator Electric Power	MWe	1,228.0	585.3	-52.3%
Thermal Power Extracted	MWt	0	1,827	-
% of Flow - MS	%	0	37.6	-
MS Flow	lbm/hr	16,037,390	14,952,560	-7%
HP Turbine Inlet Flow	lbm/hr	15,218,400	8,615,524	-43%
HP Turbine First Stage Pressure	psia	651.5	374.8	-42%
MSR Inlet Pressure	psia	190.3	104.6	-45%
LP Turbine Inlet Flow	lbm/hr	3,673,069	1,980,267	-46%
LP Turbine Inlet Pressure	psia	175.5	96.43	-45%
Condenser Duty	BTU/hr	8.21E+09	4.18E+09	-49%
Condensate Pump Flow	lbm/hr	11,334,490	11,889,450	4.9%
Heater Drain Pump Flow	lbm/hr	4,732,792	3,093,006	-35%
Feedwater Pump Flow	lbm/hr	16,067,280	14,982,480	-6.8%
Final Feedwater Temperature	°F	440.9	389.0	**-51.9°F**
Cascading Drain Flow to Condenser	lbm/hr	817,619	670,424	-18%
Cogen HX Inlet Mass Flow	lbm/hr	-	5,629,289	-

S&L 50% TPD: General Evaluations

Low Impact

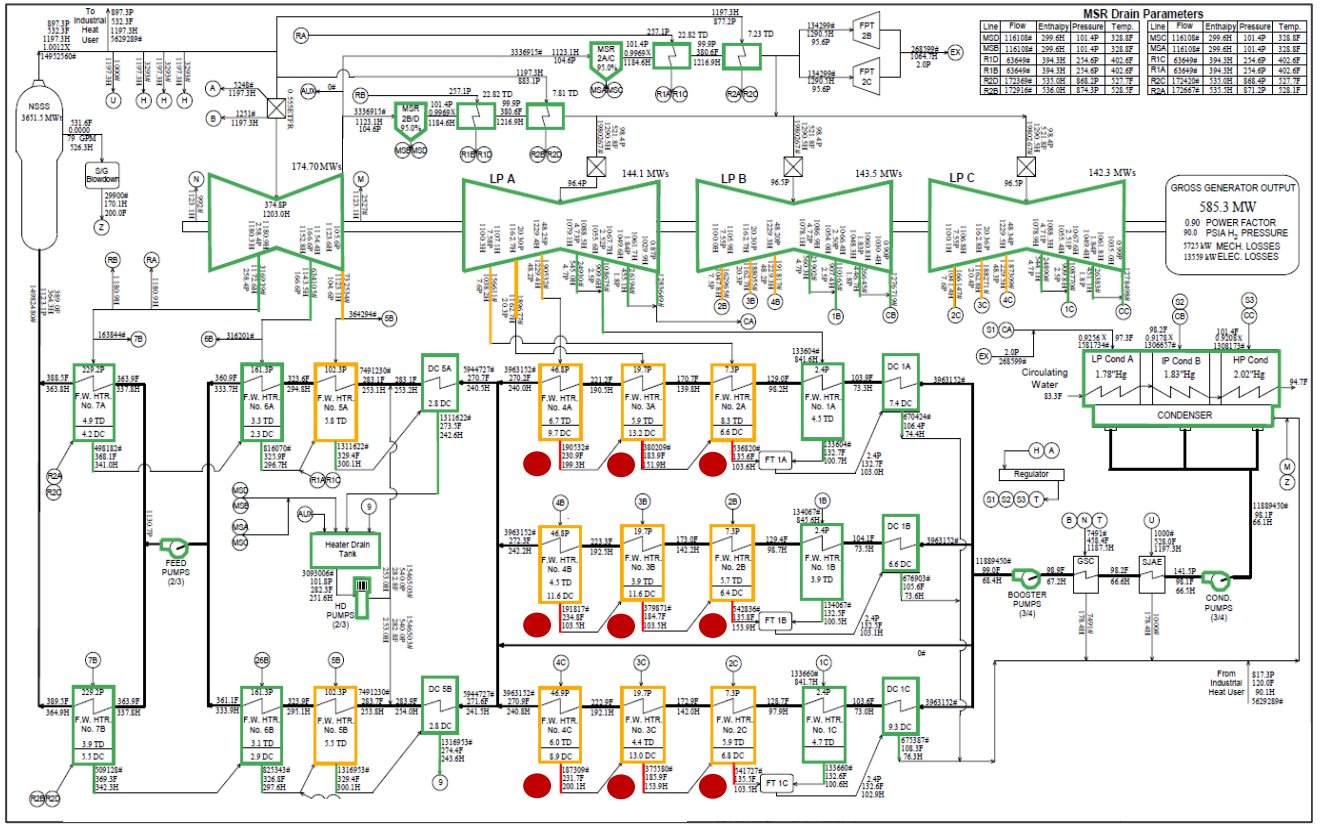
- Small Impacts for 50% thermal extraction
  - ❖ High-pressure / Low-pressure Turbines
  - ❖ Moisture Separator Reheaters (MSRs)
  - ❖ Condenser
  - ❖ Power Train Pumps
  - ❖ Heater Drain Tanks

Medium Impact

- Concerns for 50% thermal extraction
  - ❖ Feedwater Heaters (FWHs)
    - Steam inlet velocities exceed guidance
      - Flow accelerated corrosion (FAC) evaluation
      - Careful inspection to identify degradation
  - ❖ Extraction Steam Lines
    - Increased pressure drop
    - Increased liner thickness requirements → evaluation

High Impact

  - ❖ FWH Drain Control Valves (DCVs)
    - ❖ Large increases in required flow capacity (C_v) for FWH 2/3/4 normal and emergency DCVs → valve replacement
    - ❖ Possible excessive increases in required flow capacity (C_v) for FWH 2 normal DCVs based on site conditions
      - ❖ Would result in automatic plant response (opening of the FWH emergency drains)

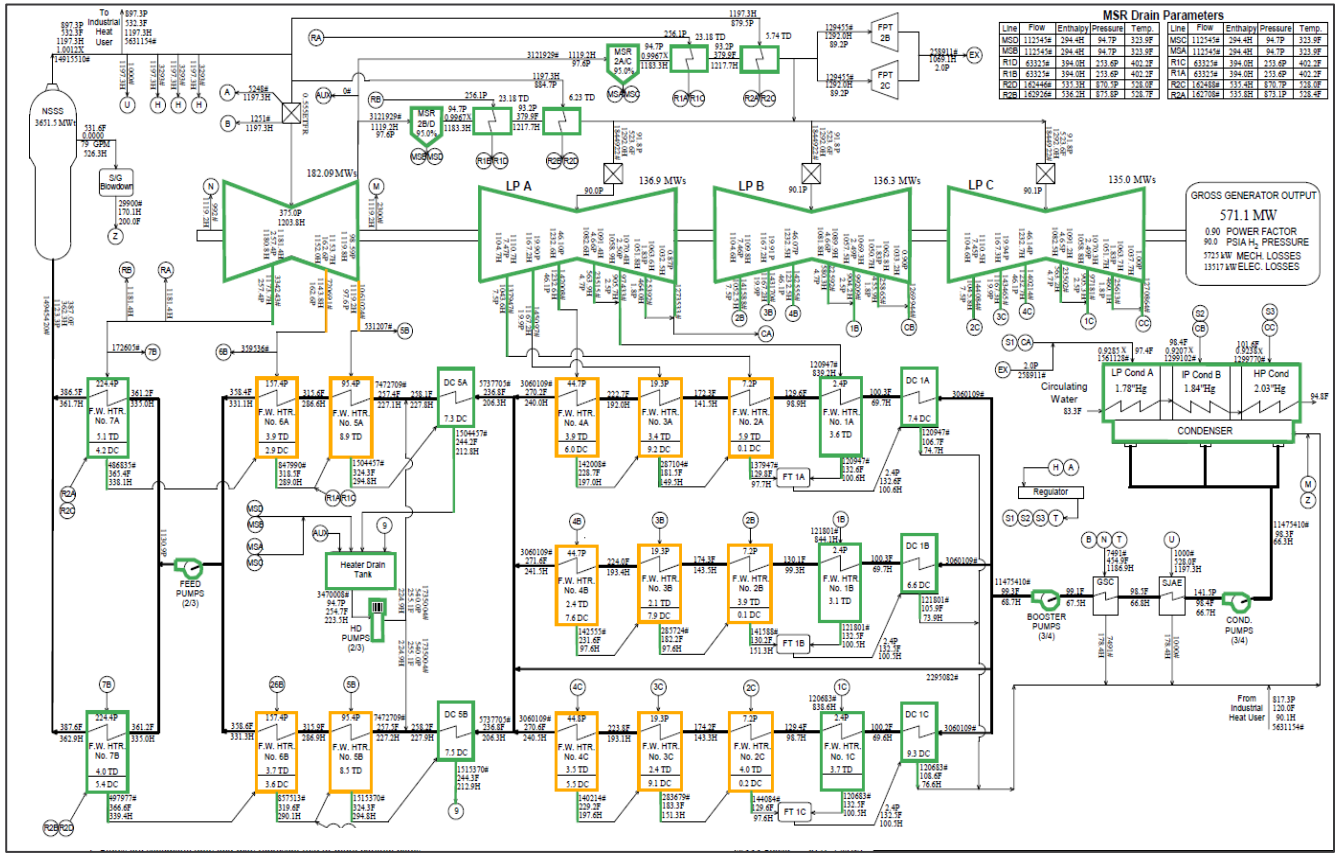


Color Coded Equipment Impacts – 50% Thermal Extraction

50% TPD Evaluation – Bypass Option

Options to address increased FWH DCV C_v requirements:

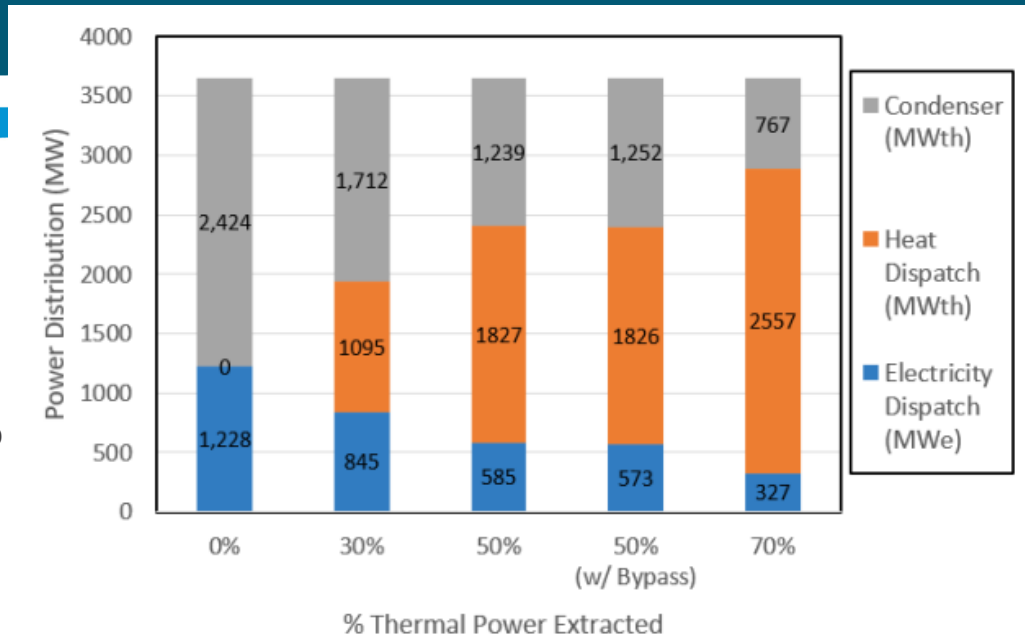
1) Valve replacement with no operational change
   - ❖ May not be feasible for all valves based on generic plant evaluation
   - ❖ Site specific evaluation may deem this option feasible
2) Valve replacement with emergency dump valve usage
   - ❖ Feasible solution which reduces impact on FWH 2/3/4 normal DCVs
   - ❖ Decreases electrical output by ~1.6 MW_e
   - ❖ Presents an operational/perception challenge
3) No valve replacement with partial LP FWH bypass
   - ❖ Removes FWH DCV issue
   - ❖ Reduces plant impact on a majority of other systems
   - ❖ Large increase in FWH #5 Extraction Steam Line Velocities
   - ❖ Decreases electrical output by ~12 MW_e
   - ❖ May require Bypass Valve upgrades to allow for specific flow control



Color Coded Equipment Impacts – 50% Thermal Extraction w/ Partial LP FWH Bypass

Low Impact Medium Impact High Impact

70% TPD Mini-Assessment
(not full assessment)



- Anticipated the MSR/HP turbine/LP turbines will perform at 25% capacity similar to 50% capacity. OEM review is necessary
- Detailed review of power train and condenser not performed. Major replacement of these components is not expected
- Steam inlet nozzle velocities exceed HEI guidelines for point heaters 2-6. Drain inlet mass flux parameters for various heaters exceed the guidelines

  → Indicates over-stressing of impingement plates
- Extraction steam line pressure drops increase due to greater velocities, with lines to feedwater heaters 3-5 seeing increases of over 150%
- Existing expansion joints require evaluation and possibly replacement
- Normal FWH 2 and 3 drains are incapable of passing the required flow and multiple FWH drain control valves (DCVs) may require greater flow passing capability through either replacement or emergency dump to the condenser, along with operational changes to address the valve limitations.

Summary of Results

- **30% and 50% Thermal Extraction is Feasible**
  - Operational changes may be required on a site-specific basis
    - Partial LP FWH Bypass
      - Minimizes negative equipment impacts
      - Decreases plant efficiency
    - FWH 2/3/4 Normal DCV Trim/Valve Replacement
    - FWH 2/3 Emergency Dumps to Condenser
- **High Impact Systems**
  - FWHs 2/3/4/5/6
  - Extraction Steam lines from HP/LP turbines to FWH 2/3/4/5/6
  - FWH 2/3/4 DCVs
    - Impacts are nullified through partial LP FWH bypass
  - Final Feedwater Temperature to SG
    - Further evaluation required to assess impacts to reactor core and controls response
- **Site specific evaluations would be required**
  - Conclusions may differ based on differences between generic reference plant and applicable station
- **50% Thermal extraction may be impractical. 70% Thermal extraction appears impractical.**

Sustaining National Nuclear Assets

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