



# Engineering Evaluation of an Integrated Off-gas System for a UNF Processing Facility

April 2021

*Changing the World's Energy Future*

Amy K Welty, Nick Soelberg, Stephanie Bruffey



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# Engineering Evaluation of an Integrated Off-gas System for a UNF Processing Facility

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UK/US Off-Gas Technical Exchange  
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U.S. DEPARTMENT OF  
**ENERGY**

# Outline

- **Scope**
- **Motivation**
- **Assumptions**
- **Key Findings**
- **Follow-on Analysis**

# Overarching aims of evaluation

- This analysis is an initial engineering evaluation and design of the off-gas abatement systems required for future used nuclear fuel (UNF) reprocessing facilities.
- This engineering study is conceptual and not tied to a specific UNF processing facility.
  - Intended to assess the complexity and sizes of the required systems.
- It evaluates:
  - (1) relative equipment sizes,
  - (2) energy requirements,
  - (3) key instrumentation requirements, and
  - (4) the extent to which key design data are, or are not, available for the off-gas systems.
- Only addresses the designs of the head-end off-gas (HOG), dissolver off-gas (DOG), and vessel off-gas (VOG) systems.
  - HOG and DOG systems are considered with and without tritium pretreatment.

**Engineering Evaluation  
of an Integrated Off-Gas  
Treatment System for  
Used Nuclear Fuel  
Reprocessing Facilities**

Fuel Cycle Research & Development

Prepared for  
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Materials Recovery and Waste Form Development  
Campaign  
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(b)(7)(BV), (b)(7)(BW), (b)(7)(BX), (b)(7)(BY), (b)(7)(BZ), (b)(7)(CA), (b)(7)(CB), (b)(7)(CC), (b)(7)(CD), (b)(7)(CE), (b)(7)(CF), (b)(7)(CG), (b)(7)(CH), (b)(7)(CI), (b)(7)(CJ), (b)(7)(CK), (b)(7)(CL), (b)(7)(CM), (b)(7)(CN), (b)(7)(CO), (b)(7)(CP), (b)(7)(CQ), (b)(7)(CR), (b)(7)(CS), (b)(7)(CT), (b)(7)(CU), (b)(7)(CV), (b)(7)(CW), (b)(7)(CX), (b)(7)(CY), (b)(7)(CZ), (b)(7)(DA), (b)(7)(DB), (b)(7)(DC), (b)(7)(DD), (b)(7)(DE), (b)(7)(DF), (b)(7)(DG), (b)(7)(DH), (b)(7)(DI), (b)(7)(DJ), (b)(7)(DK), (b)(7)(DL), (b)(7)(DM), (b)(7)(DN), (b)(7)(DO), (b)(7)(DP), (b)(7)(DQ), (b)(7)(DR), (b)(7)(DS), (b)(7)(DT), (b)(7)(DU), (b)(7)(DV), (b)(7)(DW), (b)(7)(DX), (b)(7)(DY), (b)(7)(DZ), (b)(7)(EA), (b)(7)(EB), (b)(7)(EC), (b)(7)(ED), (b)(7)(EE), (b)(7)(EF), (b)(7)(EG), (b)(7)(EH), (b)(7)(EI), (b)(7)(EJ), (b)(7)(EK), (b)(7)(EL), (b)(7)(EM), (b)(7)(EN), (b)(7)(EO), (b)(7)(EP), (b)(7)(EQ), (b)(7)(ER), (b)(7)(ES), (b)(7)(ET), (b)(7)(EU), (b)(7)(EV), (b)(7)(EW), (b)(7)(EX), (b)(7)(EY), (b)(7)(EZ), 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(b)(7)(IF), (b)(7)(IG), (b)(7)(IH), (b)(7)(II), (b)(7)(IJ), (b)(7)(IK), (b)(7)(IL), (b)(7)(IM), (b)(7)(IN), (b)(7)(IO), (b)(7)(IP), (b)(7)(IQ), (b)(7)(IR), (b)(7)(IS), (b)(7)(IT), (b)(7)(IU), (b)(7)(IV), (b)(7)(IW), (b)(7)(IX), (b)(7)(IY), (b)(7)(IZ), (b)(7)(JA), (b)(7)(JB), (b)(7)(JC), (b)(7)(JD), (b)(7)(JE), (b)(7)(JF), (b)(7)(JG), (b)(7)(JH), (b)(7)(JI), (b)(7)(JJ), (b)(7)(JK), (b)(7)(JL), (b)(7)(JM), (b)(7)(JN), (b)(7)(JO), (b)(7)(JP), (b)(7)(JQ), (b)(7)(JR), (b)(7)(JS), (b)(7)(JT), (b)(7)(JU), (b)(7)(JV), (b)(7)(JW), (b)(7)(JX), (b)(7)(JY), (b)(7)(JZ), (b)(7)(KA), (b)(7)(KB), (b)(7)(KC), (b)(7)(KD), (b)(7)(KE), (b)(7)(KF), (b)(7)(KG), (b)(7)(KH), (b)(7)(KI), (b)(7)(KJ), (b)(7)(KK), (b)(7)(KL), (b)(7)(KM), (b)(7)(KN), (b)(7)(KO), (b)(7)(KP), (b)(7)(KQ), (b)(7)(KR), (b)(7)(KS), (b)(7)(KT), (b)(7)(KU), (b)(7)(KV), (b)(7)(KW), (b)(7)(KX), (b)(7)(KY), (b)(7)(KZ), (b)(7)(LA), (b)(7)(LB), (b)(7)(LC), (b)(7)(LD), (b)(7)(LE), (b)(7)(LF), (b)(7)(LG), (b)(7)(LH), (b)(7)(LI), (b)(7)(LJ), (b)(7)(LK), (b)(7)(LL), (b)(7)(LM), (b)(7)(LN), (b)(7)(LO), (b)(7)(LP), (b)(7)(LQ), (b)(7)(LR), (b)(7)(LS), (b)(7)(LT), (b)(7)(LU), (b)(7)(LV), (b)(7)(LW), (b)(7)(LX), (b)(7)(LY), (b)(7)(LZ), (b)(7)(MA), (b)(7)(MB), (b)(7)(MC), (b)(7)(MD), (b)(7)(ME), (b)(7)(MF), (b)(7)(MG), (b)(7)(MH), (b)(7)(MI), (b)(7)(MJ), (b)(7)(MK), (b)(7)(ML), (b)(7)(MM), (b)(7)(MN), (b)(7)(MO), (b)(7)(MP), (b)(7)(MQ), (b)(7)(MR), (b)(7)(MS), (b)(7)(MT), (b)(7)(MU), (b)(7)(MV), (b)(7)(MW), (b)(7)(MX), (b)(7)(MY), (b)(7)(MZ), (b)(7)(NA), (b)(7)(NB), (b)(7)(NC), (b)(7)(ND), (b)(7)(NE), (b)(7)(NF), (b)(7)(NG), (b)(7)(NH), (b)(7)(NI), (b)(7)(NJ), (b)(7)(NK), (b)(7)(NL), (b)(7)(NM), (b)(7)(NO), (b)(7)(NP), (b)(7)(NQ), (b)(7)(NR), (b)(7)(NS), (b)(7)(NT), (b)(7)(NU), (b)(7)(NV), (b)(7)(NW), (b)(7)(NX), (b)(7)(NY), (b)(7)(NZ), (b)(7)(OA), (b)(7)(OB), (b)(7)(OC), (b)(7)(OD), (b)(7)(OE), (b)(7)(OF), (b)(7)(OG), (b)(7)(OH), (b)(7)(OI), (b)(7)(OJ), (b)(7)(OK), (b)(7)(OL), (b)(7)(OM), (b)(7)(ON), (b)(7)(OO), (b)(7)(OP), (b)(7)(OQ), (b)(7)(OR), (b)(7)(OS), (b)(7)(OT), (b)(7)(OU), (b)(7)(OV), (b)(7)(OW), (b)(7)(OX), (b)(7)(OY), (b)(7)(OZ), (b)(7)(PA), (b)(7)(PB), (b)(7)(PC), (b)(7)(PD), (b)(7)(PE), (b)(7)(PF), (b)(7)(PG), (b)(7)(PH), (b)(7)(PI), (b)(7)(PJ), (b)(7)(PK), (b)(7)(PL), (b)(7)(PM), (b)(7)(PN), (b)(7)(PO), (b)(7)(PP), (b)(7)(PQ), (b)(7)(PR), (b)(7)(PS), (b)(7)(PT), (b)(7)(PU), (b)(7)(PV), (b)(7)(PW), (b)(7)(PX), (b)(7)(PY), (b)(7)(PZ), (b)(7)(QA), (b)(7)(QB), (b)(7)(QC), (b)(7)(QD), (b)(7)(QE), (b)(7)(QF), (b)(7)(QG), (b)(7)(QH), (b)(7)(QI), (b)(7)(QJ), (b)(7)(QK), (b)(7)(QL), (b)(7)(QM), (b)(7)(QN), (b)(7)(QO), (b)(7)(QP), (b)(7)(QQ), (b)(7)(QR), (b)(7)(QS), (b)(7)(QT), (b)(7)(QU), (b)(7)(QV), (b)(7)(QW), (b)(7)(QX), (b)(7)(QY), (b)(7)(QZ), (b)(7)(RA), (b)(7)(RB), (b)(7)(RC), (b)(7)(RD), (b)(7)(RE), (b)(7)(RF), (b)(7)(RG), (b)(7)(RH), (b)(7)(RI), (b)(7)(RJ), (b)(7)(RK), (b)(7)(RL), (b)(7)(RM), (b)(7)(RN), (b)(7)(RO), (b)(7)(RP), (b)(7)(RQ), (b)(7)(RR), (b)(7)(RS), (b)(7)(RT), (b)(7)(RU), (b)(7)(RV), (b)(7)(RW), (b)(7)(RX), (b)(7)(RY), (b)(7)(RZ), (b)(7)(SA), (b)(7)(SB), (b)(7)(SC), (b)(7)(SD), (b)(7)(SE), (b)(7)(SF), (b)(7)(SG), (b)(7)(SH), (b)(7)(SI), (b)(7)(SJ), (b)(7)(SK), (b)(7)(SL), (b)(7)(SM), (b)(7)(SN), (b)(7)(SO), (b)(7)(SP), (b)(7)(SQ), (b)(7)(SR), (b)(7)(SS), (b)(7)(ST), (b)(7)(SU), (b)(7)(SV), (b)(7)(SW), (b)(7)(SX), (b)(7)(SY), (b)(7)(SZ), (b)(7)(TA), (b)(7)(TB), (b)(7)(TC), (b)(7)(TD), (b)(7)(TE), (b)(7)(TF), (b)(7)(TG), (b)(7)(TH), (b)(7)(TI), (b)(7)(TJ), (b)(7)(TK), (b)(7)(TL), (b)(7)(TM), (b)(7)(TN), (b)(7)(TO), (b)(7)(TP), (b)(7)(TQ), (b)(7)(TR), (b)(7)(TS), (b)(7)(TT), (b)(7)(TU), (b)(7)(TV), (b)(7)(TW), (b)(7)(TX), (b)(7)(TY), (b)(7)(TZ), (b)(7)(UA), (b)(7)(UB), (b)(7)(UC), (b)(7)(UD), (b)(7)(UE), (b)(7)(UF), (b)(7)(UG), (b)(7)(UH), (b)(7)(UI), (b)(7)(UJ), (b)(7)(UK), (b)(7)(UL), (b)(7)(UM), (b)(7)(UN), (b)(7)(UO), (b)(7)(UP), (b)(7)(UQ), (b)(7)(UR), (b)(7)(US), (b)(7)(UT), (b)(7)(UU), (b)(7)(UV), (b)(7)(UW), (b)(7)(UX), (b)(7)(UY), (b)(7)(UZ), (b)(7)(VA), (b)(7)(VB), (b)(7)(VC), (b)(7)(VD), (b)(7)(VE), (b)(7)(VF), (b)(7)(VG), (b)(7)(VH), (b)(7)(VI), (b)(7)(VJ), (b)(7)(VK), (b)(7)(VL), (b)(7)(VM), (b)(7)(VN), (b)(7)(VO), (b)(7)(VP), (b)(7)(VQ), (b)(7)(VR), (b)(7)(VS), (b)(7)(VT), (b)(7)(VU), (b)(7)(VV), (b)(7)(VW), (b)(7)(VX), (b)(7)(VY), (b)(7)(VZ), (b)(7)(WA), (b)(7)(WB), (b)(7)(WC), (b)(7)(WD), (b)(7)(WE), (b)(7)(WF), (b)(7)(WG), (b)(7)(WH), (b)(7)(WI), (b)(7)(WJ), (b)(7)(WK), (b)(7)(WL), (b)(7)(WM), (b)(7)(WN), (b)(7)(WO), (b)(7)(WP), (b)(7)(WQ), (b)(7)(WR), (b)(7)(WS), (b)(7)(WT), (b)(7)(WU), (b)(7)(WV), (b)(7)(WW), (b)(7)(WX), (b)(7)(WY), (b)(7)(WZ), (b)(7)(XA), (b)(7)(XB), (b)(7)(XC), (b)(7)(XD), (b)(7)(XE), (b)(7)(XF), (b)(7)(XG), (b)(7)(XH), (b)(7)(XI), (b)(7)(XJ), (b)(7)(XK), (b)(7)(XL), (b)(7)(XM), (b)(7)(XN), (b)(7)(XO), (b)(7)(XP), (b)(7)(XQ), (b)(7)(XR), (b)(7)(XS), (b)(7)(XT), (b)(7)(XU), (b)(7)(XV), (b)(7)(XW), (b)(7)(XX), (b)(7)(XY), (b)(7)(XZ), (b)(7)(YA), (b)(7)(YB), (b)(7)(YC), (b)(7)(YD), (b)(7)(YE), (b)(7)(YF), (b)(7)(YG), (b)(7)(YH), (b)(7)(YI), (b)(7)(YJ), (b)(7)(YK), (b)(7)(YL), (b)(7)(YM), (b)(7)(YN), (b)(7)(YO), (b)(7)(YP), (b)(7)(YQ), (b)(7)(YR), (b)(7)(YS), (b)(7)(YT), (b)(7)(YU), (b)(7)(YV), (b)(7)(YW), (b)(7)(YX), (b)(7)(YY), (b)(7)(YZ), (b)(7)(ZA), (b)(7)(ZB), (b)(7)(ZC), (b)(7)(ZD), (b)(7)(ZE), (b)(7)(ZF), (b)(7)(ZG), (b)(7)(ZH), (b)(7)(ZI), (b)(7)(ZJ), (b)(7)(ZK), (b)(7)(ZL), (b)(7)(ZM), (b)(7)(ZN), (b)(7)(ZO), (b)(7)(ZP), (b)(7)(ZQ), (b)(7)(ZR), (b)(7)(ZS), (b)(7)(ZT), (b)(7)(ZU), (b)(7)(ZV), (b)(7)(ZW), (b)(7)(ZX), (b)(7)(ZY), (b)(7)(ZZ)
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# Major Assumptions

- The basis of the facility design
  - Aqueous processing of UNF
  - Throughput = 1000 t/year
  - Plant operating time = 200 days/year.
  - Off-gas systems operate 365 days/year.
  - Fuel cooling time = 5 years
  - Fuel type = UOX (UO<sub>2</sub>-based fuel), 60 GWd/tIHM burnup
  - Steady state conditions.
  - Halogens other than iodine from the UNF and process chemicals are included for sizing the DOG iodine beds.
  - Maximum decontamination factors (DFs):
    - <sup>3</sup>H, <sup>14</sup>C, <sup>85</sup>Kr, and <sup>129</sup>I are those found in Jubin et al. (2012).
    - Ruthenium DF is found in Jubin et al. (2014).

# Target DFs used in analysis

**Table 1. Maximum DF values for the isotopes considered in this study**

Isotope	DF
$^3\text{H}$	200
$^{14}\text{C}$	10
$^{85}\text{Kr}$	50
$^{129}\text{I}$	3000
$^{106}\text{Ru}$	$3.0 \times 10^7$

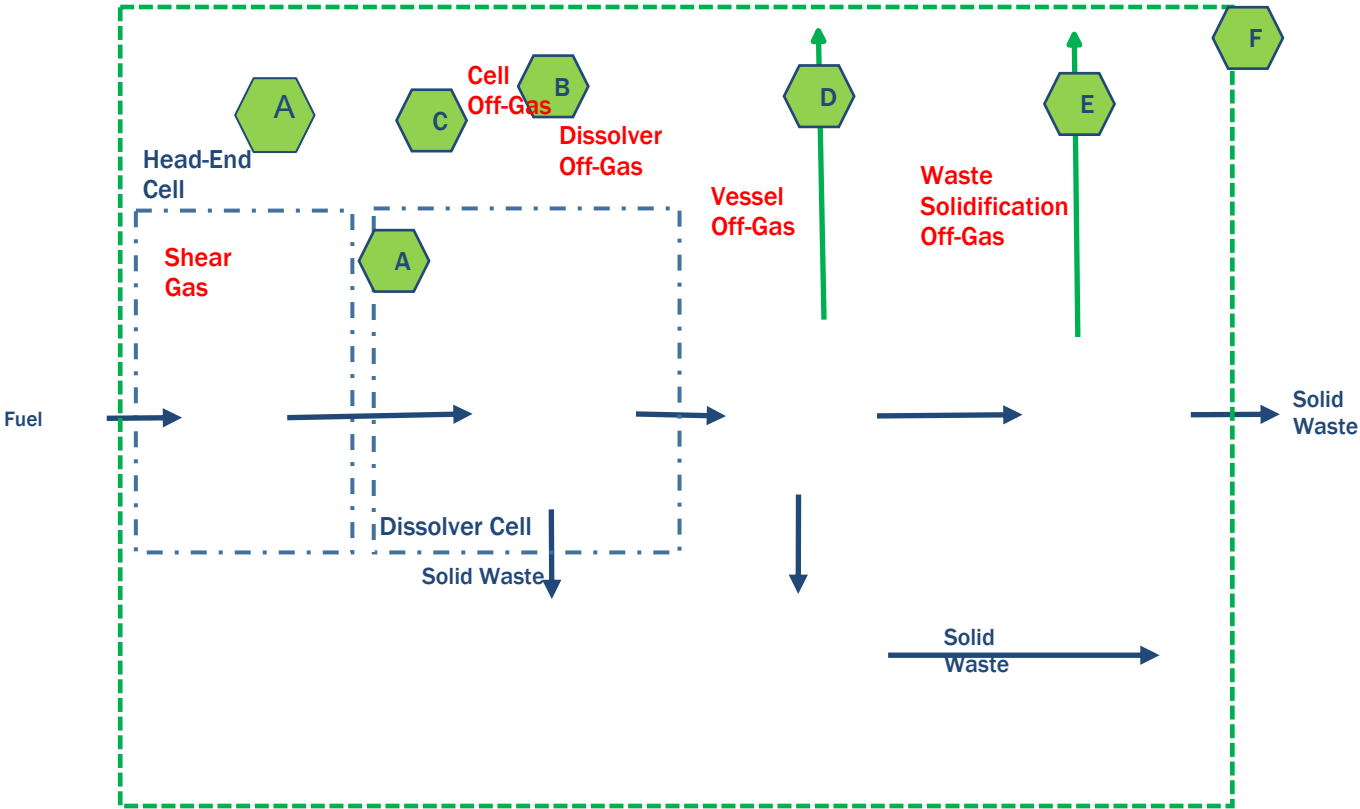
# Process design assumptions

- Tritium capture system based on two primary operating flowsheets.
  - Case 1: Base case UNF dissolution.
  - Case 2: Adds air tritium pretreatment (TPT).
    - A NO<sub>x</sub>-based TPT, being studied because it may be more efficient, is addressed in a separate report.
- Iodine capture analysis addresses iodine distribution throughout the facility and iodine speciation.
  - Silver mordenite (AgZ)
  - Silver-functionalized silica-aerogel (Ag-Aerogel) (Matyáš et al. 2011)
- Removal of NO<sub>x</sub> is based on acid/water scrubbing.

# Process design assumptions

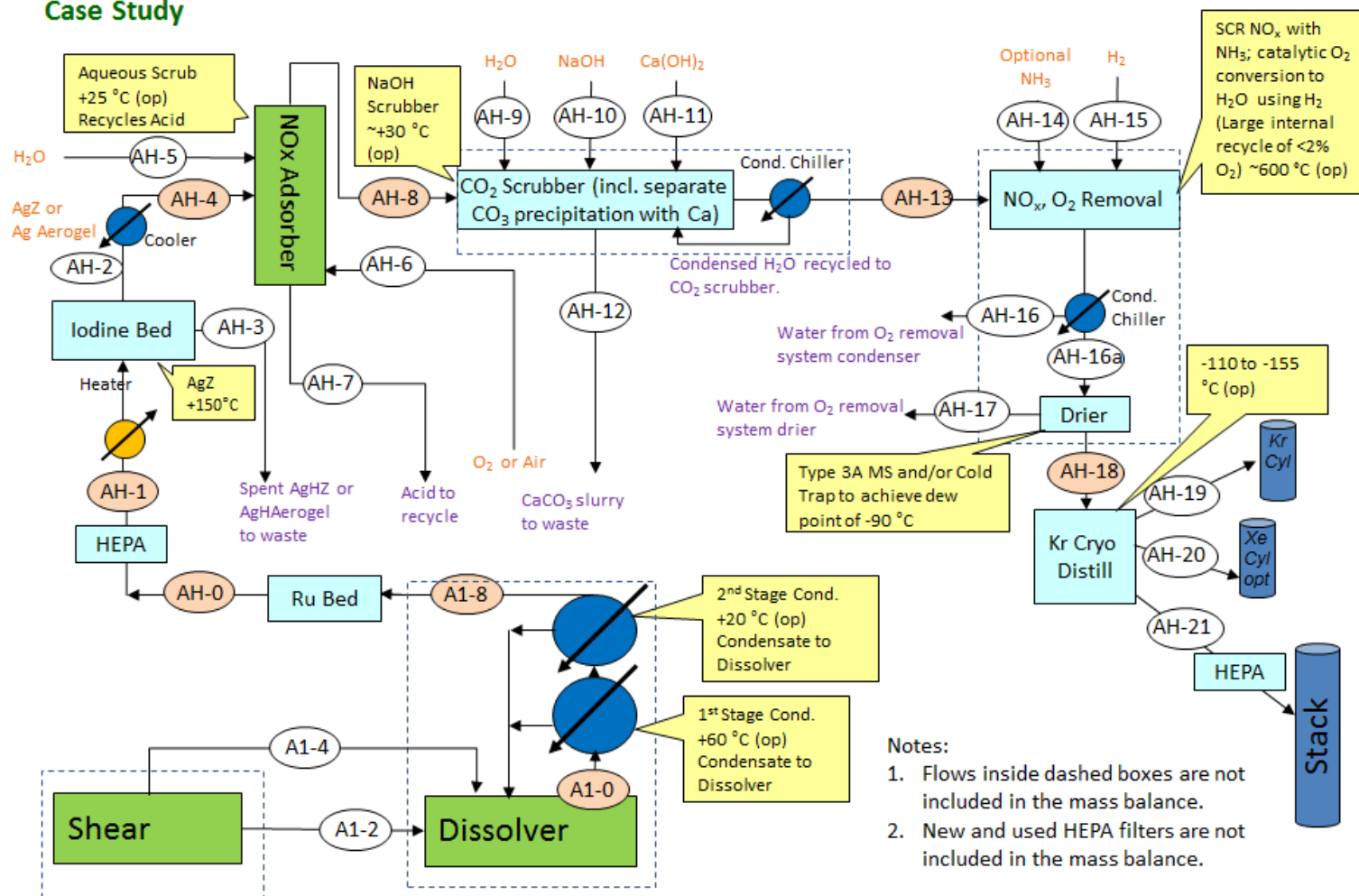
- Caustic scrubbing is used for the removal of  $^{14}\text{C}$  (e.g.,  $^{14}\text{CO}_2$ ).
- Both cryogenic and sorbent-based capture systems for noble gas capture are evaluated.
- Tramp species are included.
  - Halogens (fluorine, chlorine, etc) from process chemicals.
  - Water vapor and  $\text{CO}_2$  in the plant air.
- The effects of extended operations on equipment size and design are considered.
  - Where possible, sorbent beds are designed for greater than a 6 month operating lifetime.

# Process streams considered



# Aqueous head-end and DOG Base Case

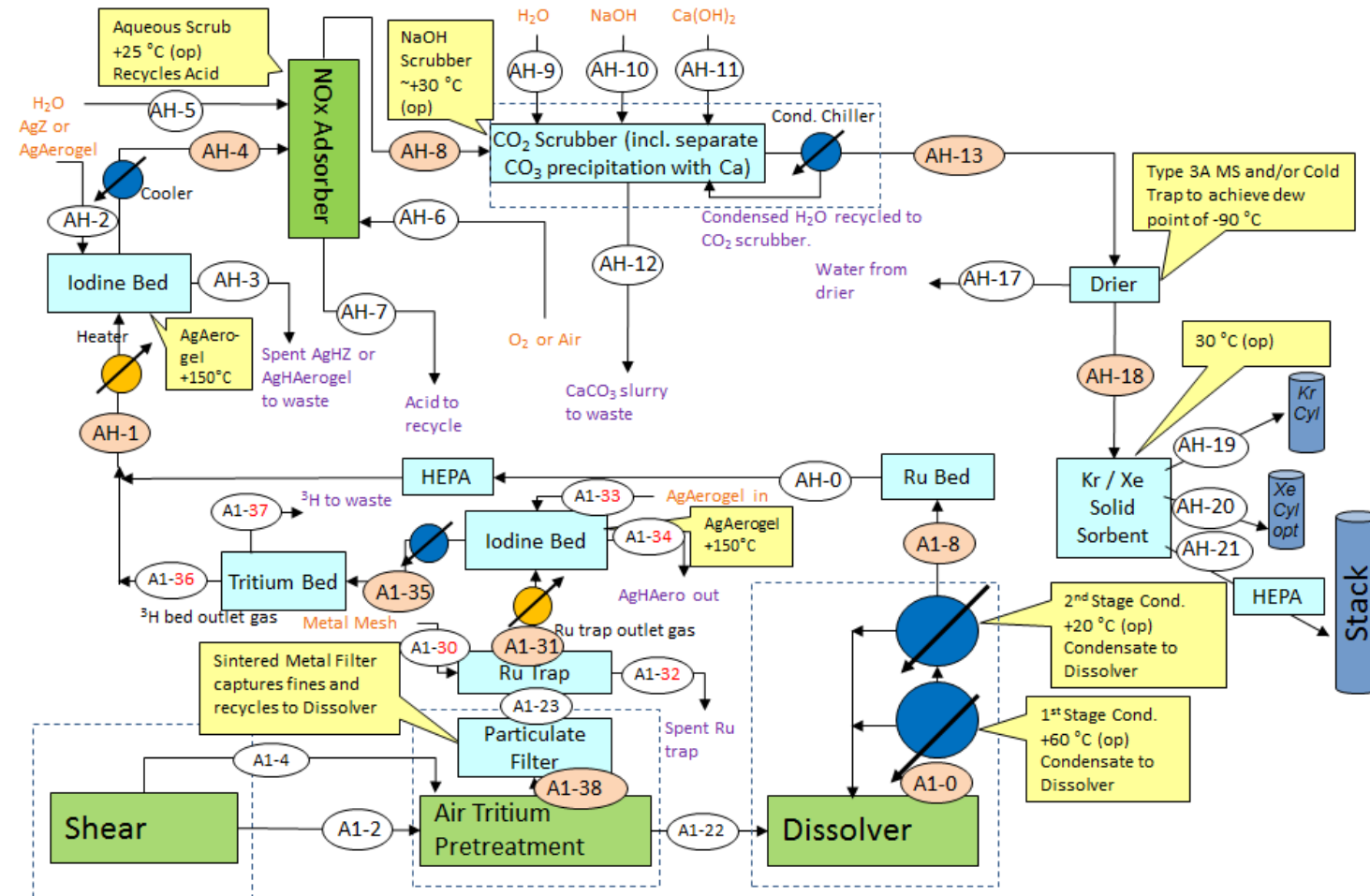
## Aqueous Head-end and Dissolver Off-gas Systems (No TPT) Case Study



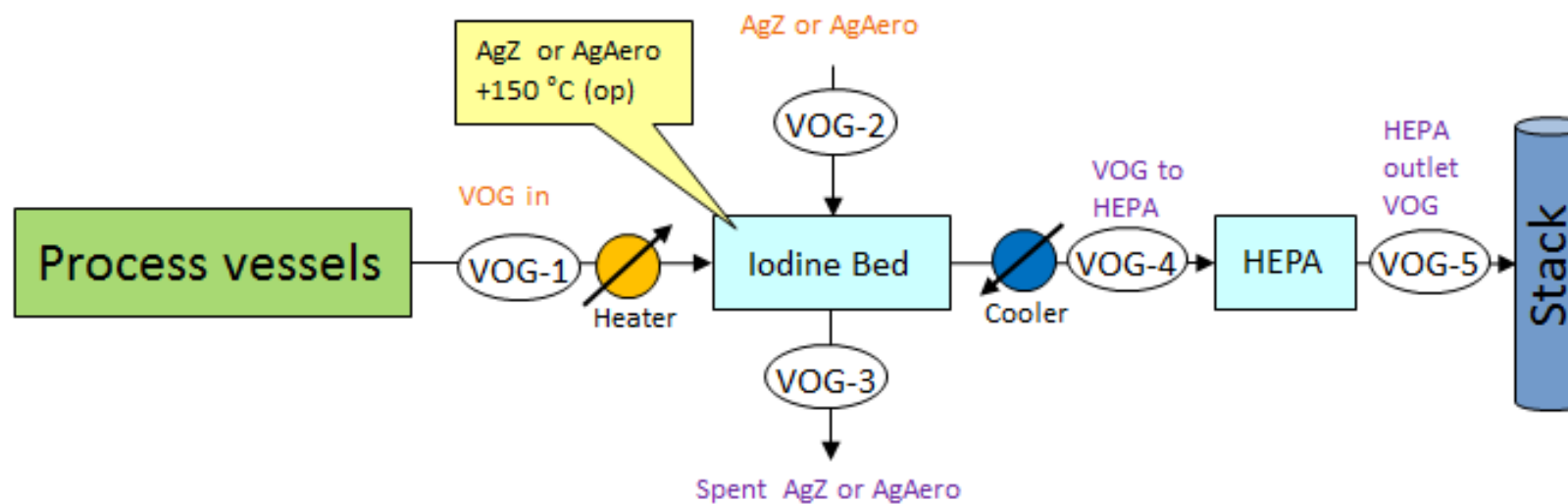
# Aqueous head-end and DOG with air tritium pretreatment

## Aqueous Head-end and Dissolver Off-gas Systems

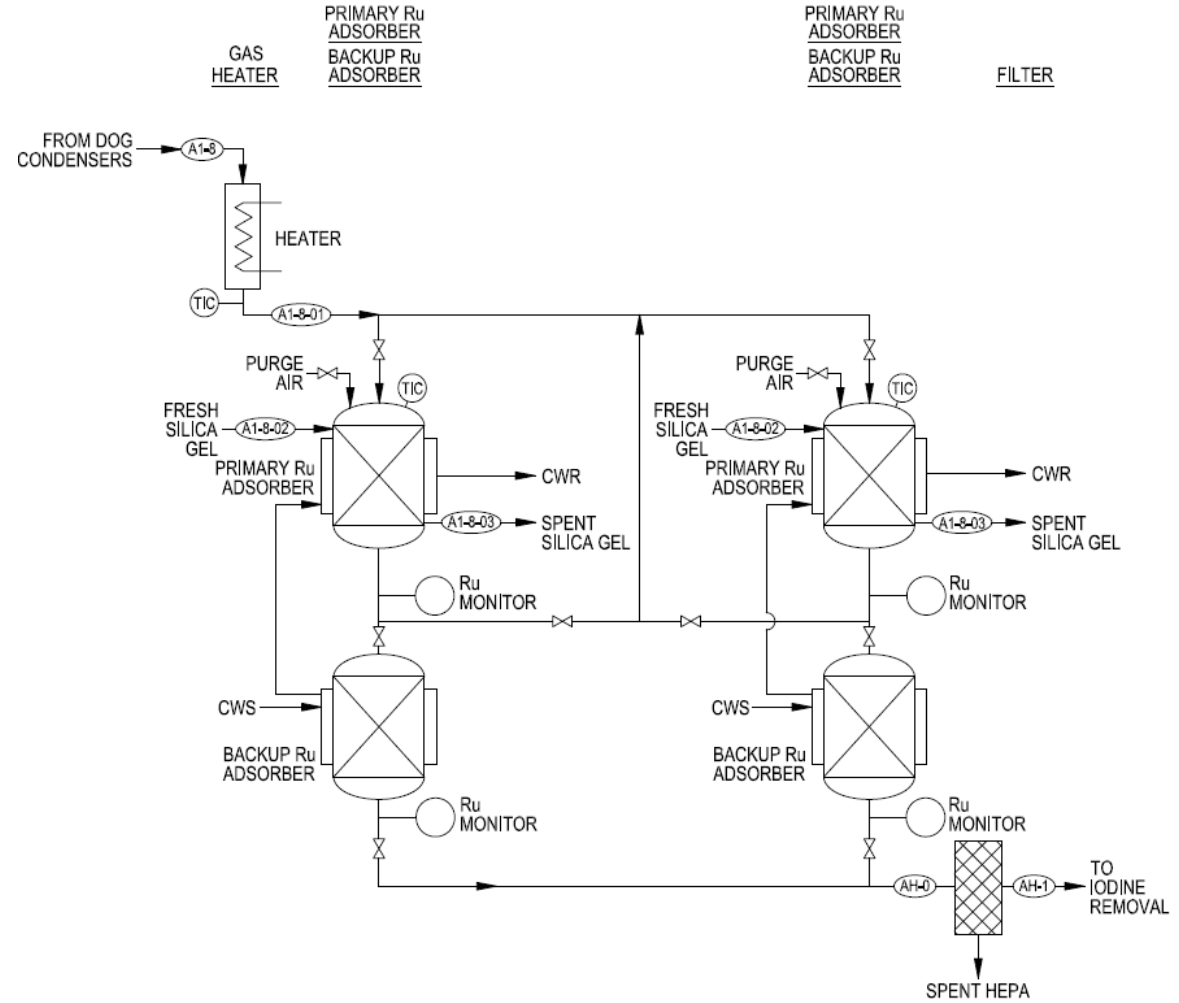
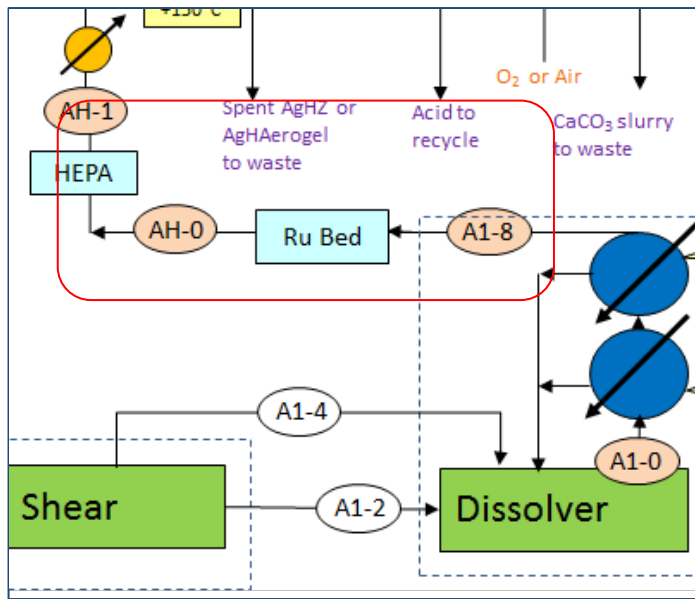
### Near-Term Target Case #1, Air Tritium Pretreatment



# Vessel off-gas system

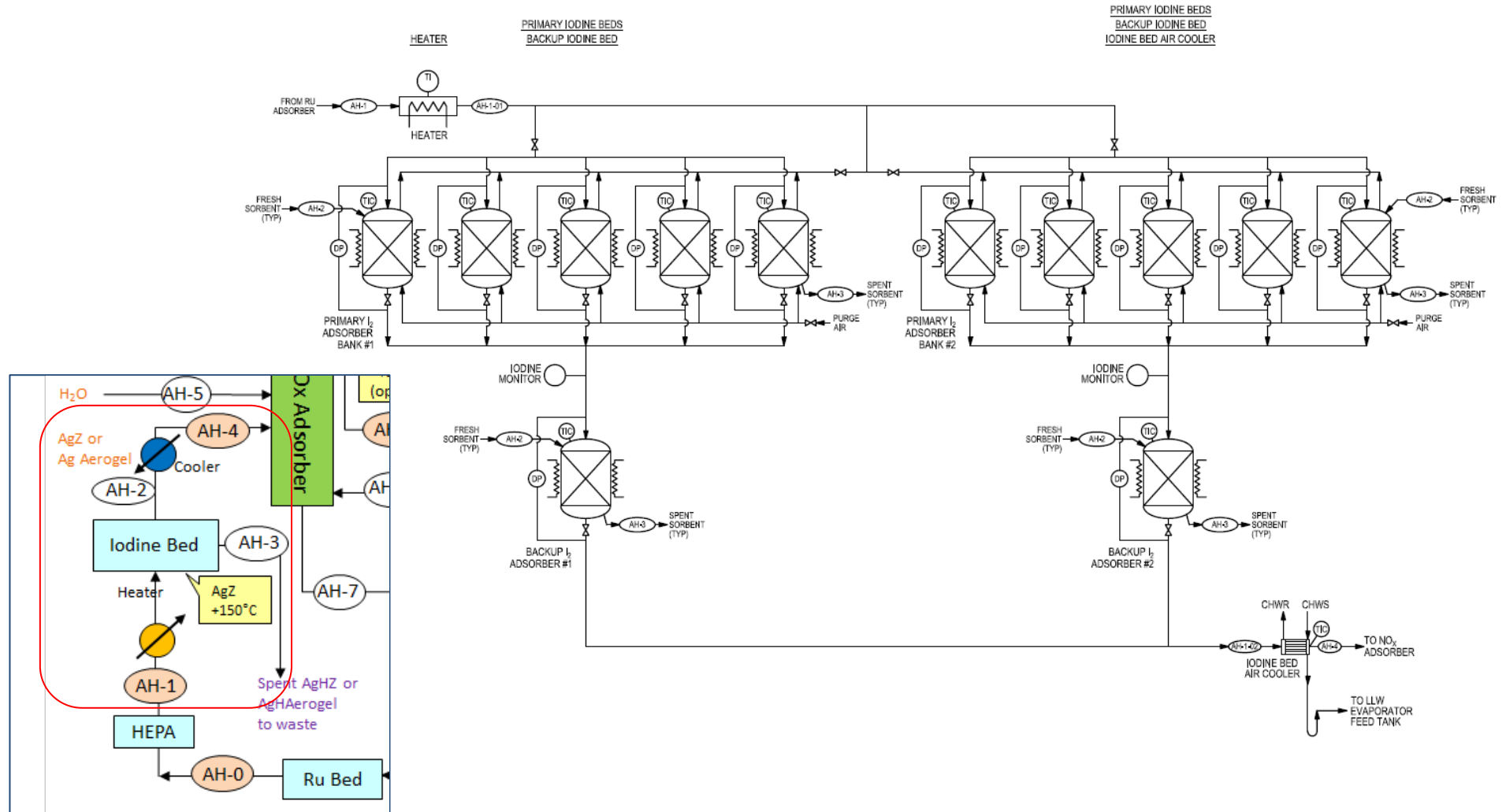


# Ruthenium removal

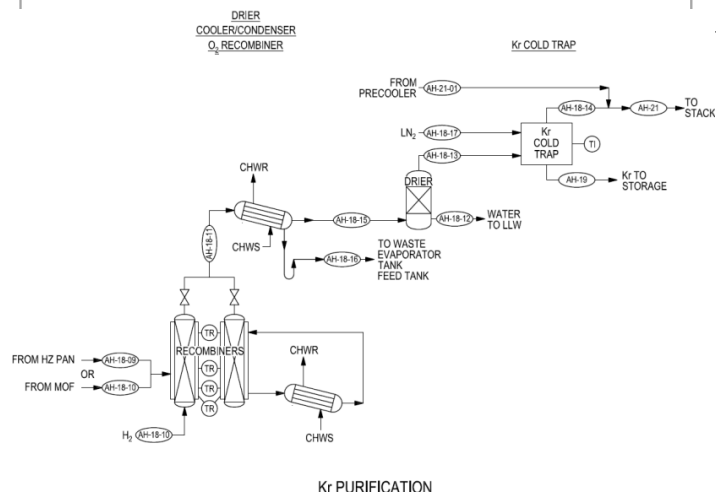
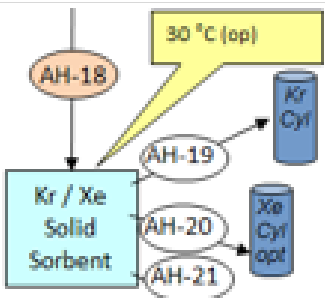
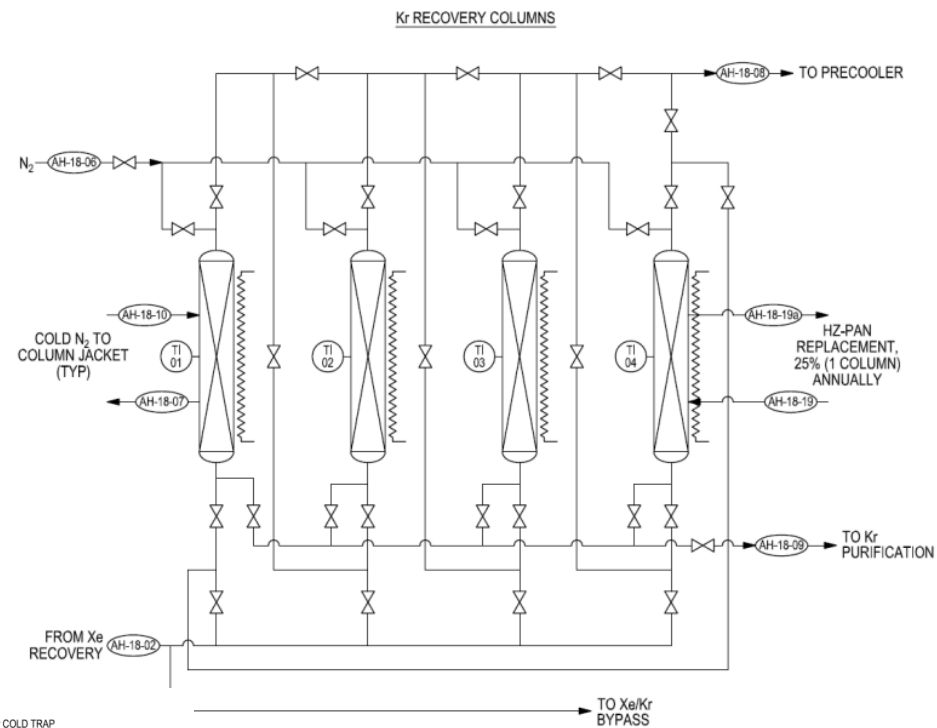
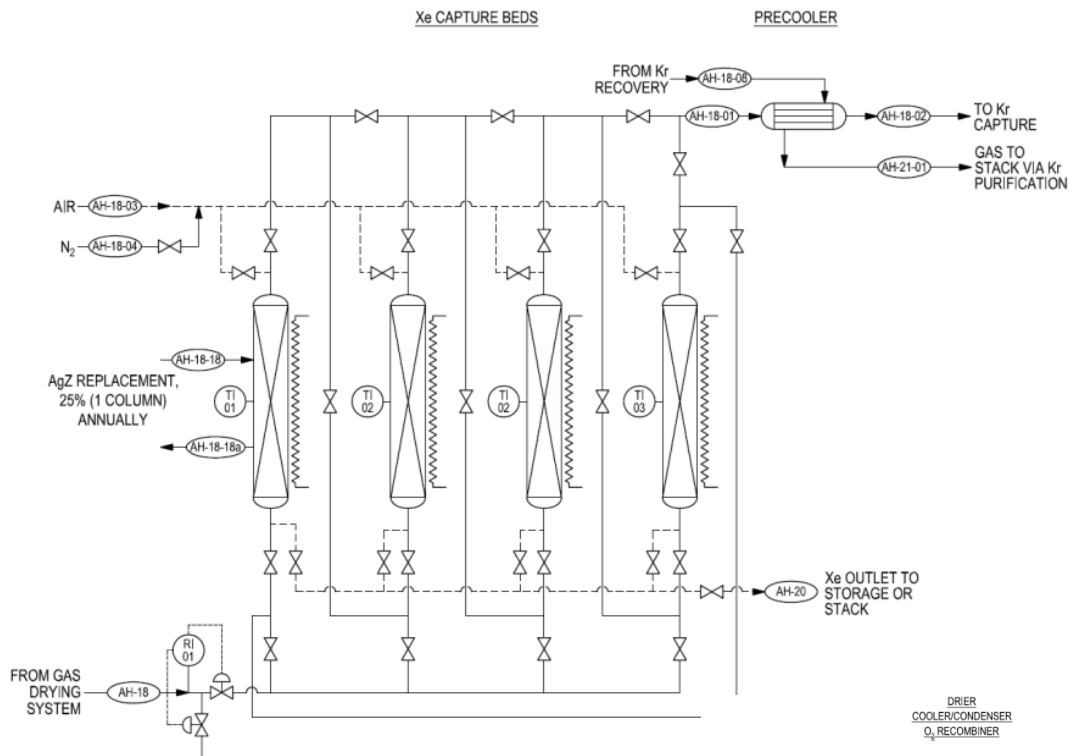


## RUTHENIUM REMOVAL DISSOLVER OFF-GAS

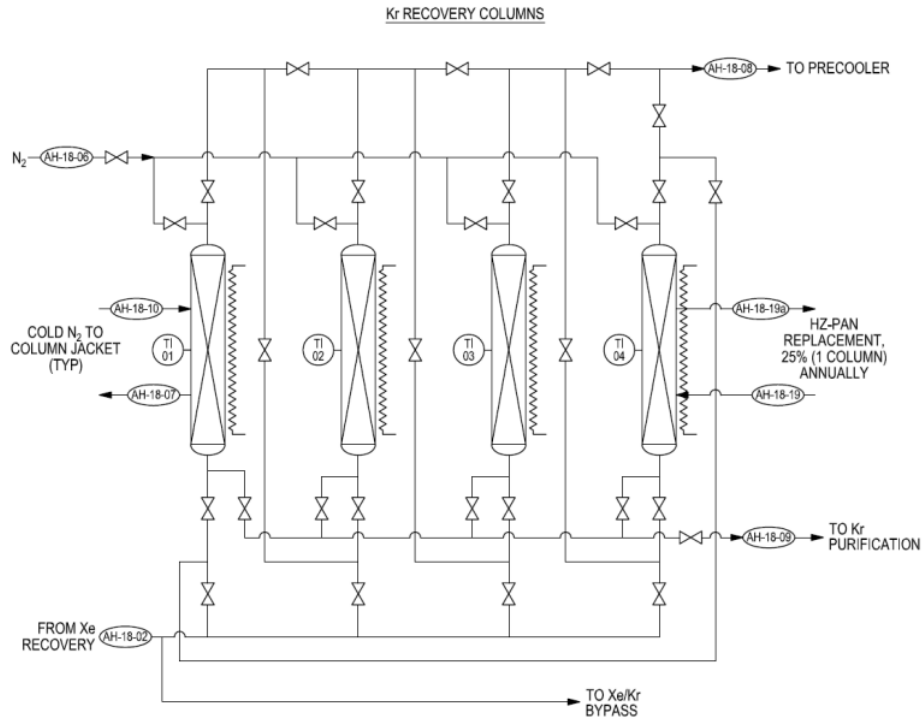
# DOG iodine removal



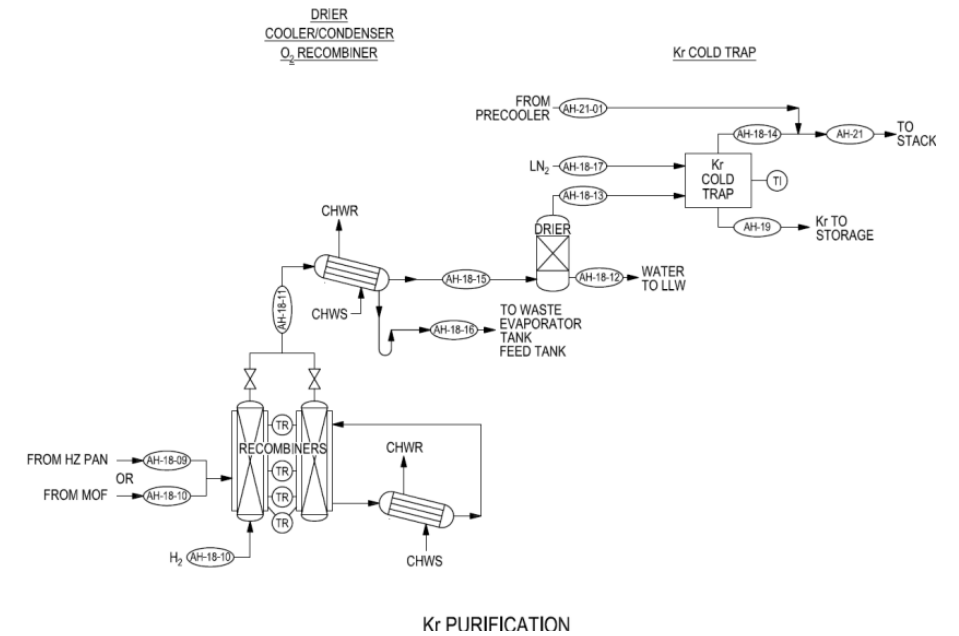
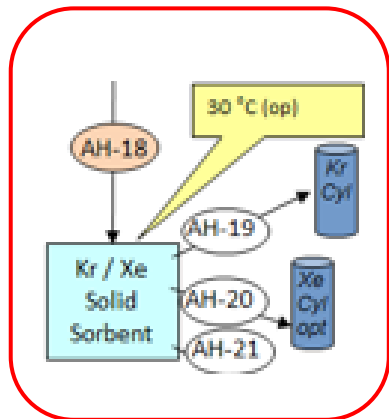
# Kr/Xe removal



# Kr/Xe removal



Kr CAPTURE (HZ-PAN)



Kr PURIFICATION

# Additional

- Energy balance and recovery were not evaluated.
- Gas and water cycle/recycle were not evaluated.
- The possibility of installing by-passes around equipment for use when there is insufficient volatile radioactive species present to warrant treatment should be investigated.
- Subsequent studies should add similar assessments for the cell off-gas (COG) and melter off-gas (MOG) systems.

# Questions/Comments

