Appendix 1. Existing AI applications to nuclear material production critical equipment and to non-nuclear industry integrable to the nuclear material production

Application	Critical equipment	Industrial applications of AI	
		Internal (nuclear)	External (non-nuclear)
Nuclear material production critical stage: enrichment			
Gas centrifuge rotating components	Rotor tube and assemblies	N/A	- AD: diagnose rotor fault in accordance with different phases (Nath et al. 2021) - AD & AO: improve machine security and inform Operator of rotor service needs through automatic centrifuge rotor state recognition (Chen 2013)
	Gas centrifuge	- AD: construct a digital representation or simulation of the chemical separations component to determine anomalies, failures, and trends (Kerman 2022a)	- AO: monitor and adjust the performance of centrifuges in the olive oil production processes (Funes et al. 2009; Jiménez et al. 2008; Menesklou et al. 2021)
	Rings or bellows	N/A	N/A
	Baffles	- AO: study the influence of four construction variables, including the dimension of the rotating baffle, to optimize centrifuge performance (Migliavacca et al. 2002) - AO: study the optimal arrangement of scoops and rotating baffles, to optimize centrifuge performance (Migliavacca et al. 1999)	N/A
	Top and bottom caps	N/A	N/A
Gas centrifuge static components	Magnetic suspension bearings	N/A	N/A
	Dampers & bearings	N/A	- AD: monitor and diagnose faults of bearings, sensors, lubrication, seals, and remanufacturing (SKF 2020)
	Molecular pumps	N/A	- AO: monitor and adjust the performance of vacuum pumps (Pal 2016)

	Motor stators	N/A	- AD: monitor and fault identification scheme for motor (Vinoth Kumar et al. 2018)
	Centrifuge housings/ recipients	N/A	N/A
	Scoops	- AO: study the optimal arrangement of scoops and rotating baffles, to optimize centrifuge performance (Migliavacca et al. 1999)	N/A
Gas centrifuge plant auxiliary systems, equipment, and components	Feed, product, and tail withdrawal systems	N/A	N/A
	Machine header piping systems	N/A	- AO: improve design, using predictive models, of early-stage piping systems (Telci 2021)
	UF6 mass spectrometers /ion sources	N/A	N/A
	Frequency changers	N/A	N/A
	Gaseous diffusion barriers	N/A	N/A
	Diffuser housing	N/A	N/A
	Compressors and gas blowers	N/A	- AO: model "blade profiles with specified performance metrics and operating and manufacturing constraints" (University of London City n.d.) - AO: model 2D and 3D profiles of compressor blades (Xu et al. 2023)
	Rotary shaft seals	N/A	N/A
	Heat exchangers (for cooling UF6)	N/A	- AO: model and estimate the outlet temperatures of working fluid through heat exchangers (Mohan 2020)
Gaseous diffusion enrichment auxiliary systems, equipment, and components	Feed, product, and tail withdrawal systems	N/A	N/A
	Header piping systems	N/A	- AO: improve design, using predictive models, of early-stage piping systems (Telci 2021)
	Vacuum systems	N/A	N/A

	Shut-off and control valves	N/A	- AD: monitor and diagnose valve fault (Shelly n.d.) - AO: model and estimate valve performance based on flow performance parameters (Jadhav 2018)
Aerodynamic enrichment plant auxiliary systems, equipment, and components	Separation nozzles	N/A	N/A
	Vortex tubes	N/A	- AO: monitor and adjust the performance of vortex tubes (Pouraria 2016) - AO: optimize performance of vortex tubes (Agarwal et al. 2020)
	Compressors and gas blowers	N/A	- AO: model "blade profiles with specified performance metrics and operating and manufacturing constraints" (University of London City n.d.) - AO: model 2D and 3D profiles of compressor blades (Xu et al. 2023)
	Rotary shaft seals	N/A	N/A
	Heat exchangers (for gas cooling)	N/A	- AO: model and estimate the outlet temperatures of working fluid through heat exchangers (Mohan 2020)
	Separation element housings	N/A	N/A
	Feed systems / product and tail withdrawal systems	N/A	N/A
	Header piping systems	N/A	- AO: improve design, using predictive models, of early-stage piping systems (Telci 2021)
	Vacuum systems and pumps	N/A	- AO: monitor and adjust the performance of vacuum pumps (Pal 2016)
	Shut-off and control valves	N/A	- AD: monitor and diagnose valve fault (Shelly n.d.) - AO: model and estimate valve performance based on flow performance parameters (Jadhav 2018)
	UF6 mass spectrometers / ion sources	N/A	N/A

	UF6 gas separation systems	N/A	N/A
Exchange enrichment plant auxiliary systems, equipment, and components	Liquid-liquid exchange columns (chemical exchange)	N/A	N/A
	Liquid-liquid centrifugal contactors (chemical exchange)	N/A	N/A
	Feed preparation systems (Chemical exchange)	N/A	N/A
	Uranium oxidation systems (chemical exchange)	N/A	N/A
	Fast-reacting ion exchange resins/ absorbents (ion exchange)	- AO: map existing relations between nucleus radius and resin's exchange time efficiency to find most ideal pellicular dimension (Cabral et al. 2005)	N/A
	Ion exchange columns (ion exchange)	N/A	N/A
	Ion exchange reflux systems (ion exchange)	N/A	N/A
Laser-based enrichment plant systems, equipment, and components	Uranium vaporization system (Atomic vapor laser isotope separation [AVLIS])	N/A	N/A
	Liquid uranium metal handling system (AVLIS)	N/A	N/A
	Uranium metal 'product' and 'tails' collector assemblies (AVLIS)	N/A	N/A

	Separator module housings (AVLIS)	N/A	N/A
	Supersonic expansion nozzles (Molecular laser isotope separation [MLIS])	N/A	N/A
	Uranium pentafluoride product collectors (MLIS)	N/A	N/A
	UF6/carrier gas compressors (MLIS)	N/A	- AO: model "blade profiles with specified performance metrics and operating and manufacturing constraints" (University of London City n.d.) - AO: model 2D and 3D profiles of compressor blades (Xu et al. 2023)
	Rotary shaft seals (MLIS)	N/A	N/A
	Fluorination systems (MLIS)	N/A	N/A
	UF6 mass spectrometers / ion sources (MLIS)	N/A	N/A
	Feed withdrawal systems (MLIS)	N/A	N/A
	Laser systems (ALVIS, MLIS, Chemical reaction by isotope selective laser activation [CRISLA])	N/A	N/A
Plasma separation enrichment plants	Microwave power sources and antenna	N/A	N/A

systems, equipment, and components	Ion excitation coils	N/A	- AD: condition monitoring and fault detection of superconducting apparatuses in large-scale power applications (Yazdani-Asrami et al. 2022) - AO: improve design, using predictive models, of superconducting apparatuses (Yazdani-Asrami et al. 2022)
	Uranium plasma generation systems	N/A	N/A
	Liquid uranium metal handling system	N/A	N/A
	Uranium metal "product" and "tails" collector assemblies	N/A	N/A
	Separator module housings	N/A	N/A
Nuclear material production critical stage: reprocessing			
Reprocessing components	NM flow verification	- AO: develop real-time tracking of spent fuel material flow within a given facility (General Electric n.d.c.)	N/A
	Plasma separation applied to reprocessing	N/A	- AD: condition monitoring and fault detection of superconducting apparatuses in large-scale power applications (Yazdani-Asrami et al. 2022) - AO: improve design, using predictive models, of superconducting apparatuses (Yazdani-Asrami et al. 2022)
	Dissolvers	N/A	N/A
	Metal cutting shears	N/A	N/A

	Solvent extractors	- AO: characterize stages within solvent extraction process to increase target metals recovery, indicate process faults, account for special nuclear material, and inform near real-time decision making (Kerman 2022b) - AO: process improvement through identification of better design alternatives for determining pH level and chemical structures of dissolved nuclear fuel (Papich 2021)	- AO: improve design with aim of lowering activation barrier of the rearrangement reaction (Gastegger 2021)
	Chemical holding or storage vessels	N/A	N/A
	Plutonium nitrate to oxide conversion systems	N/A	N/A
	Plutonium oxide to metal production system	N/A	N/A
	Hydrogen fluoride	N/A	N/A
	Ceramic crucibles	N/A	- AO: confirm accuracy of AI based modeling of Al2O3 nanoparticles reinforced with A356 matrix composites (Shabani et al. 2012)

Sources: Authors' compilation based on selective open-source analysis (AD-Anomaly Detection; AO-Anomaly Optimization. Automated Discovery remains in the early research stage without a publicly known application to equipment in nuclear or non-nuclear industry and therefore is excluded from the table.) Note: Appendix 1 is a template that is offered to better understand the application of AI to the nuclear material production, and it does not provide a complete review of the nuclear material production process. However, it is envisioned that researchers could use this template as a means to further this research.