Kairos Power

Kairos Power Atlas Fuel Fabrication Facility Pre-Application Meeting

December 14, 2021

Kairos Power's mission is to enable the world's transition to clean energy, with the ultimate goal of dramatically improving people's quality of life while protecting the environment.

In order to achieve this mission, we must prioritize our efforts to focus on a clean energy technology that is *affordable* and *safe*.

Atlas Fuel Fabrication Facility Presentation

- Introduction and Opening Remarks
- Kairos Power
- Kairos Power Fuel Design
- Fabrication Facility Scope
- Key Fuel Fabrication Processes
- Overview of Proposed Facility
- Regulatory Approach

Overview of Kairos Power

- Nuclear energy engineering and design company ***singularly focused*** on the commercialization of the fluoride salt-cooled high temperature reactor (FHR)
  - Founded in 2016
  - Current Staffing
    - 232 Employees
    - ~90% Engineering Staff
- Private funding commitment to engineering design and licensing program and physical demonstration through nuclear and non-nuclear technology development program
- Schedule driven by US demonstration by 2030 (***or earlier***) and rapid deployment ramp in 2030s
- Cost targets set to be competitive with natural gas in the US electricity market

Kairos Power Headquarters

Kairos Power Team

Kairos Power Locations

HQ / R-Lab / S-Lab
Alameda, CA

T-Facility / Engineering Test Unit
Production Development Facility
Albuquerque, NM

Kairos Power | MATERION

Molten Salt Pilot Plant
Elmore, OH

Hermes Reactor
Atlas Fuel Production Facility
Oak Ridge, TN

Licensing Office
Charlotte, NC

Kairos Power Facilities

Kairos Power Highlights

Dec. 2016
Kairos Power starts business operations

Sep. 2018
RAPID Lab operations begin

Feb. 2020
Kairos Power acquires Albuquerque manufacturing & testing facility

May 2020
Decision to build Hermes non-power reactor is made

Sep. 2017
Site selection for KP-HQ and R-Lab in Alameda Point

Oct. 2018
Pre-application engagement with NRC begins

Mar. 2020
Kairos Power forms strategic partnership w/ Materion to supply beryllium fluoride

Jul. 2020
Salt Lab is commissioned in Alameda

Kairos Power Highlights

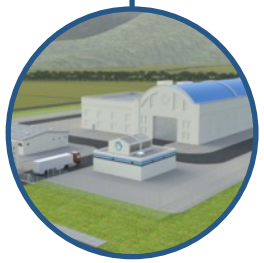
Dec. 2020
Kairos Power wins $303M DOE ARDP award. T-Facility construction begins. Site announced for Hermes reactor in Tennessee

Jun. 2021
T-Facility completed. First non-nuclear pebble manufactured in PDL

Nov. 2021
ETU vessel delivered to KP-SW

Jan. 2021
Pebble Development Lab construction begins

May 2021
Cooperative development agreement with TVA



Sept./Oct. 2021
CPA for Hermes reactor submitted to NRC

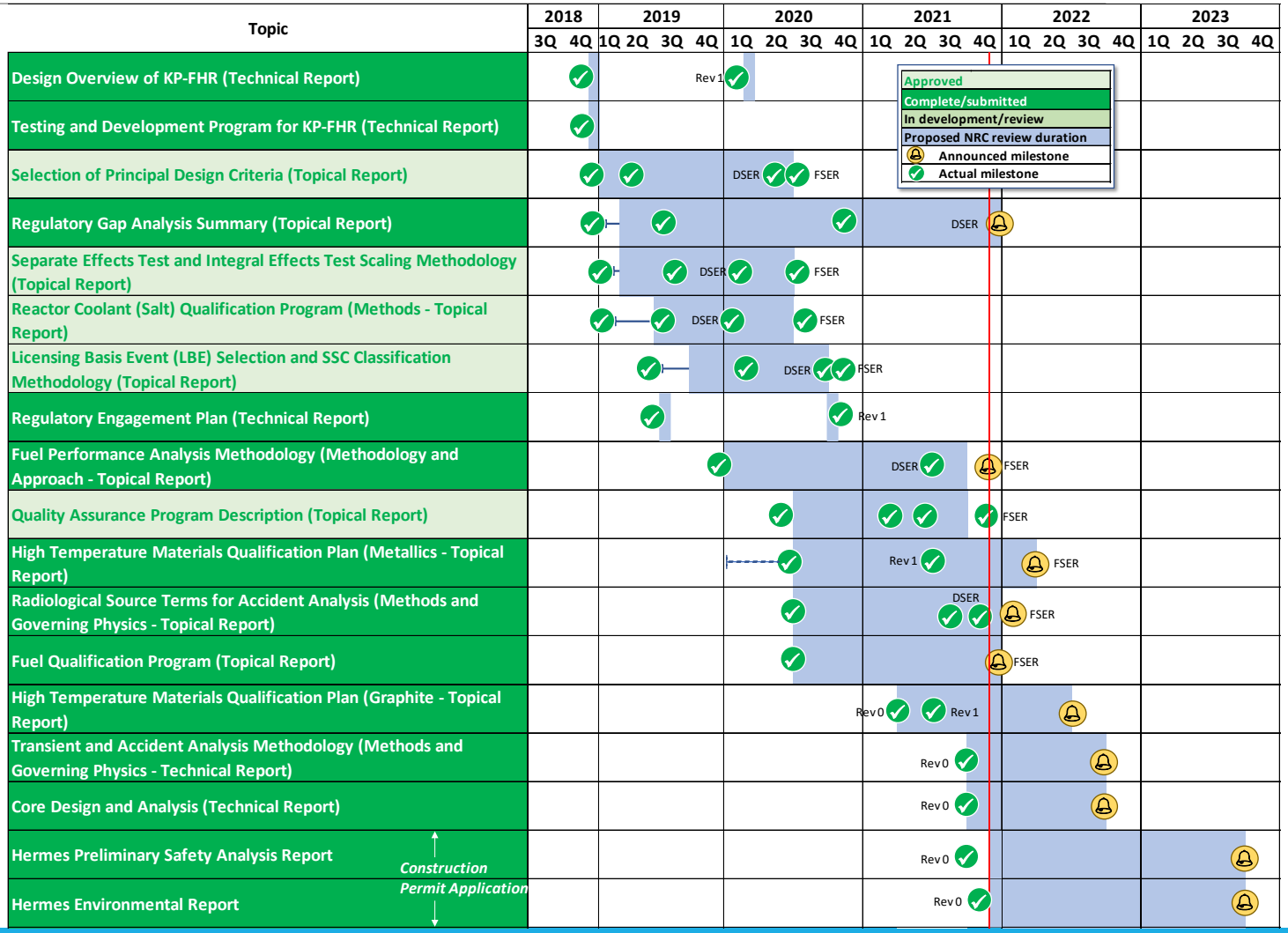
Technology Basis
Fluoride Salt-Cooled High-Temperature Reactor (FHR)

Coated Particle Fuel
TRISO

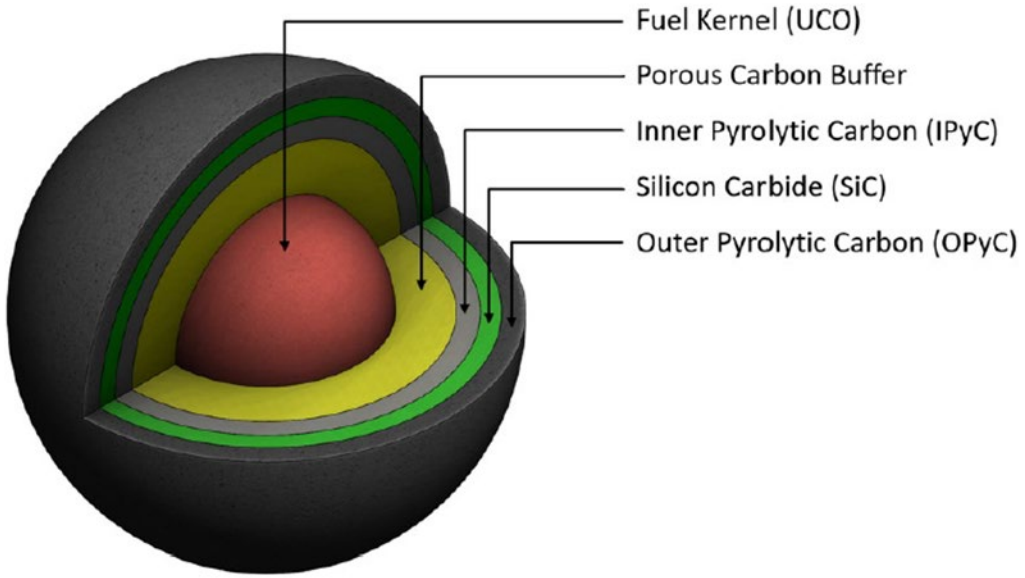
Liquid Fluoride Salt Coolant
Flibe ($2LiF\text{-}BeF_2$)

Kairos Power NRC Status

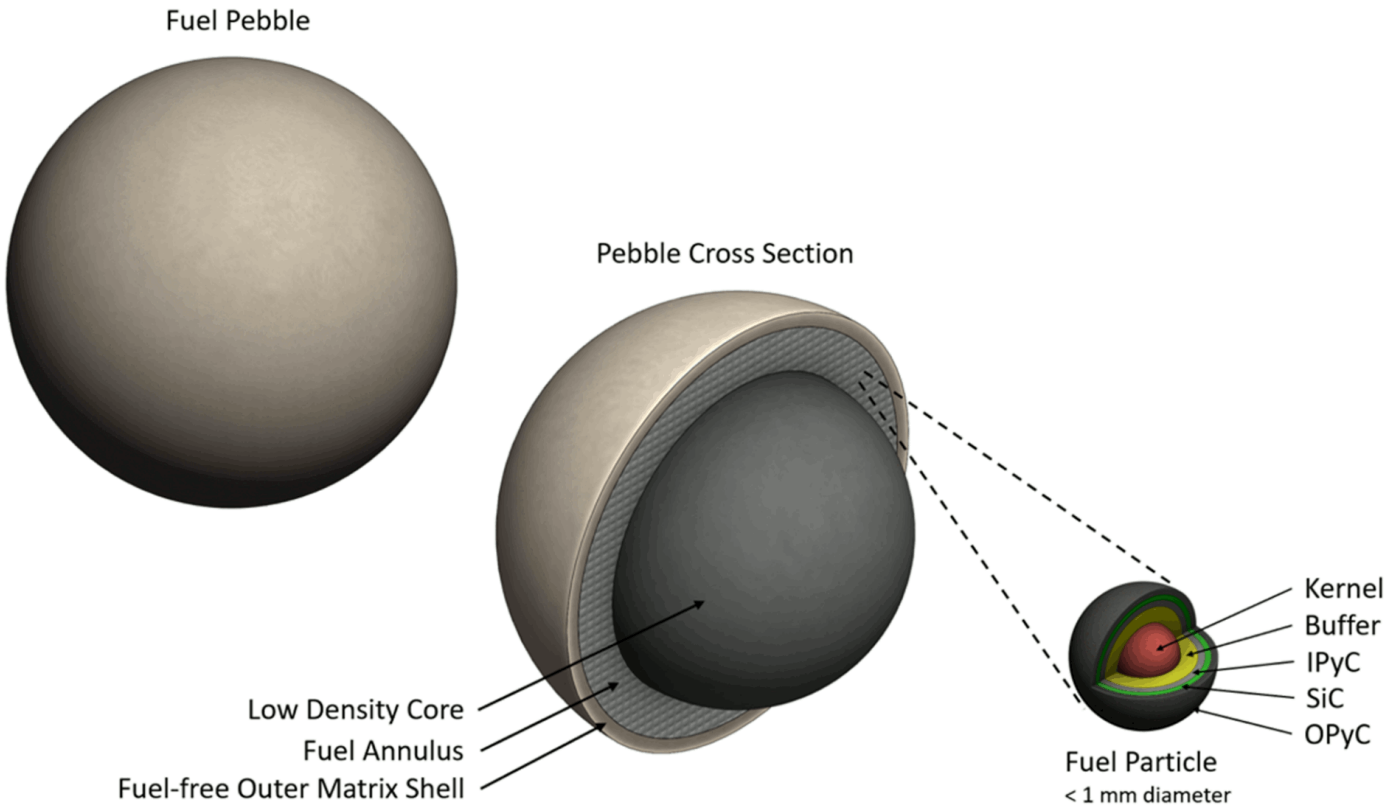
- ***Construction Permit Application accepted for review***
- 11 topical reports to date with multiple iterations and five technical reports
- Multiple audits, onsite reviews (including PIRT acceptance)
- ACRS review of several topicals
- **NRC topical report approvals:**
  - Principal Design Criteria
  - Test Scaling Methodology
  - Salt Coolant Qualification
  - Licensing Basis Event Selection
  - Quality Assurance
- **Topical reports under review:**
  - Regulatory Analysis
  - Fuel Performance
  - High-Temp Metallic Materials
  - Mechanistic Source Term
  - Fuel Qualification
  - High-Temperature Graphite Materials



Tri-structural Isotropic (TRISO) Coated Particles



Fuel Pebble and Particle



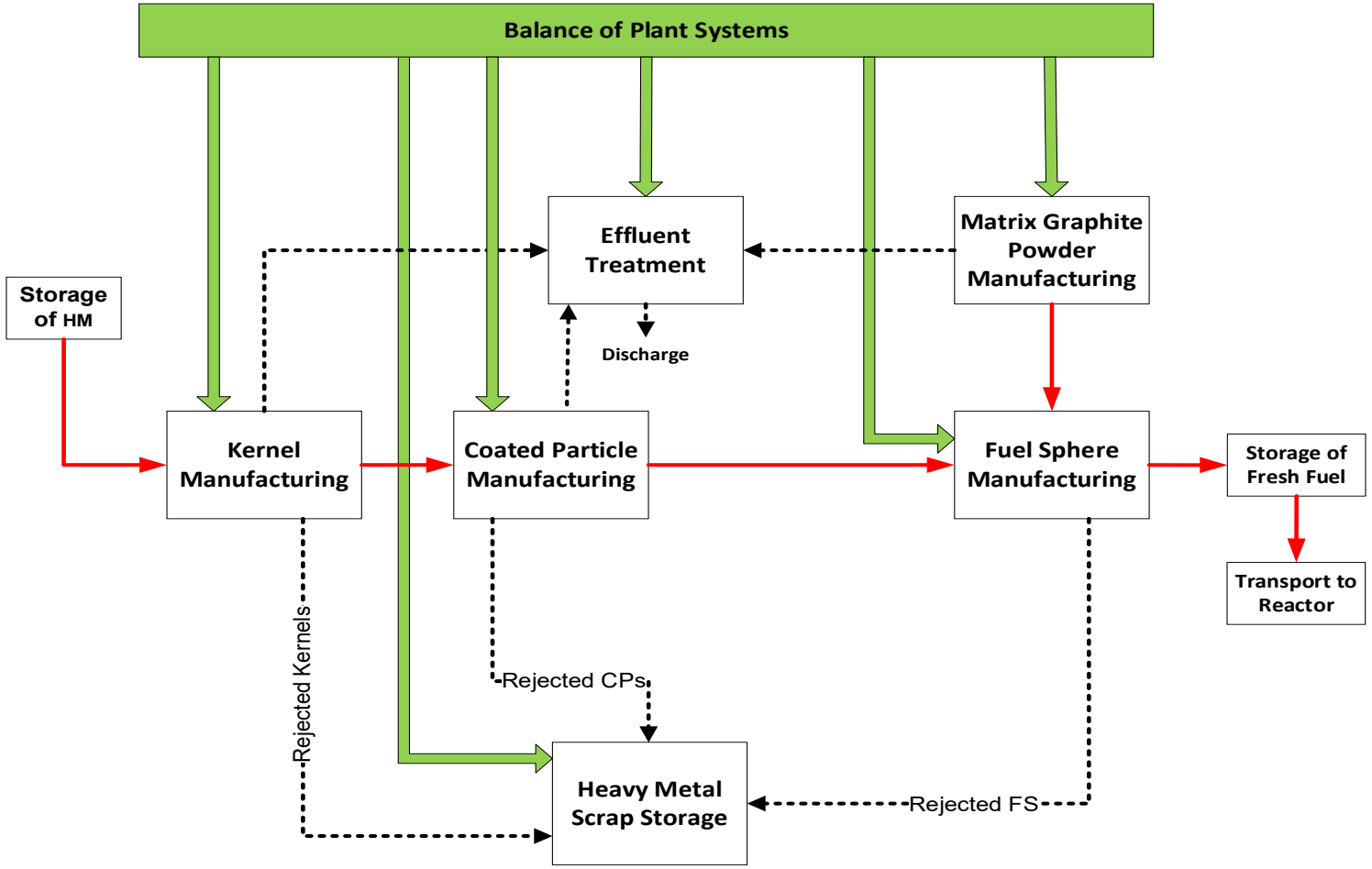
Atlas Fuel Fabrication Facility Scope

- Scope of the facility is to manufacture HALEU TRISO particles and annular pebbles (containing TRISO particles)
- Atlas will be a Category II facility under the regulations in 10 CFR 70 and will be located near the Hermes demonstration test reactor at the East Tennessee Technology Park in Oak Ridge, Tennessee
  - Facility will not perform enrichment
- Currently developing TRISO and pebble manufacturing equipment designs and processes

Fuel Fabrication Process Overview

- Kernel Manufacturing
  - Dissolution of the U_3O_8 powder
  - Preparation of a uranium casting solution
  - Casting of spherical uranium kernels
  - Aging, washing, and drying and of the kernels
  - Calcining and sintering to convert the kernels to UCO (UO_2 + UC + UC_2)
  - Sieving, sorting, sampling, portioning to separate out only the spherical kernels
- Coated Particle Manufacturing
  - Deposition using chemical vapor deposition of multiple carbon and SiC layers on the uranium kernel
  - Separation and handling of the soot from the CVD coater
  - Graphite component handling
- Pebble Manufacturing
  - Matrix graphite powder preparation
  - Pebble pressing and heat treating
- Waste Management
  - Recovery and treatment of the effluent waste streams from the various process steps, plus solid waste handling
  - Heavy metal recovery (collection and storage)
  - Off-gas treatment
- Balance of Plant
  - Utility and service systems
    - Gases, reagents, waters, and power supply
    - HVAC, process ventilation, fire, gas, radiological protection systems
  - Civil and Structural
    - Process areas, offices, change rooms
  - General and Support
    - Communications, facility monitoring, security, decontamination, Maintenance, emergency response

Facility Process Overview

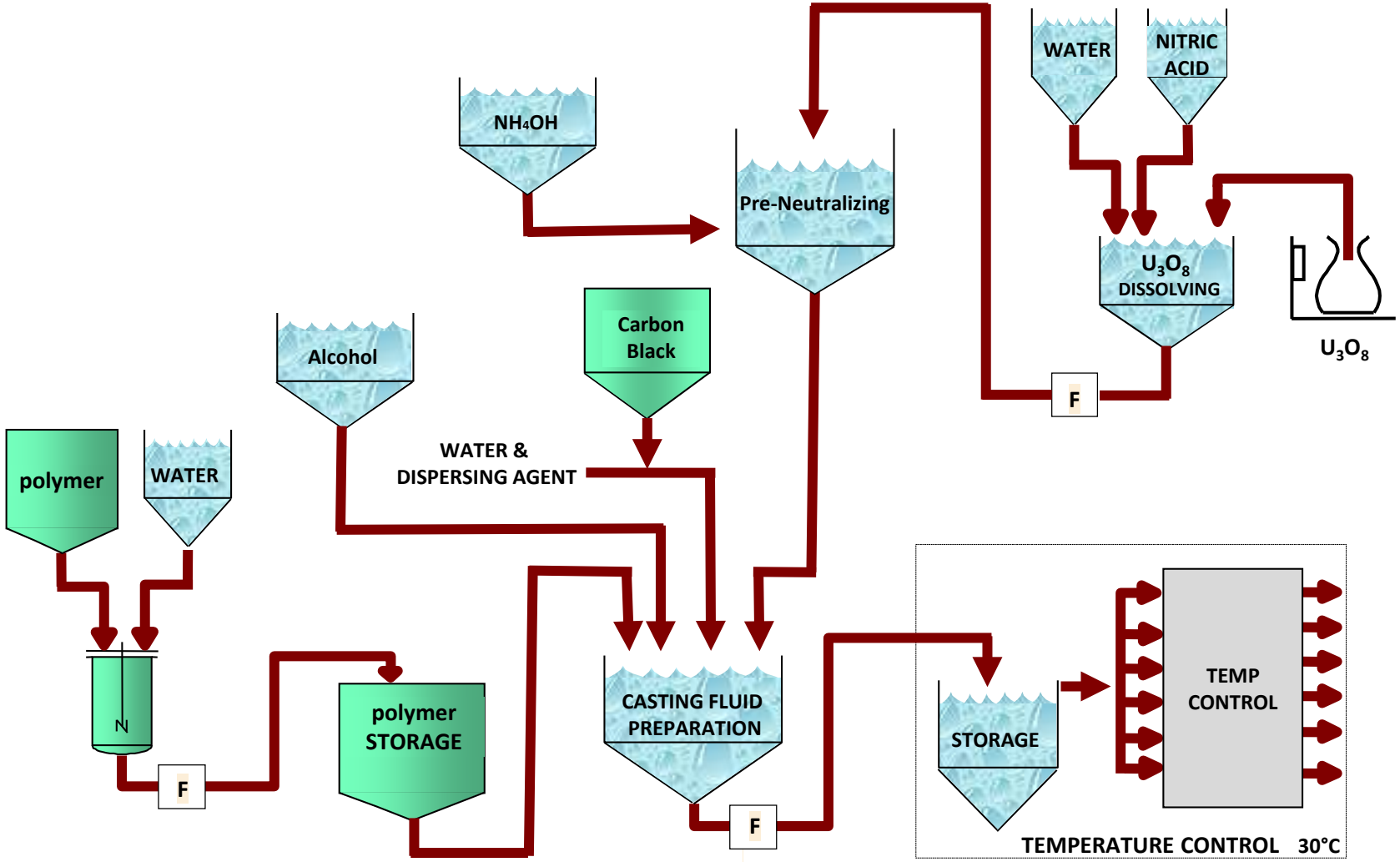


Kernel Manufacturing

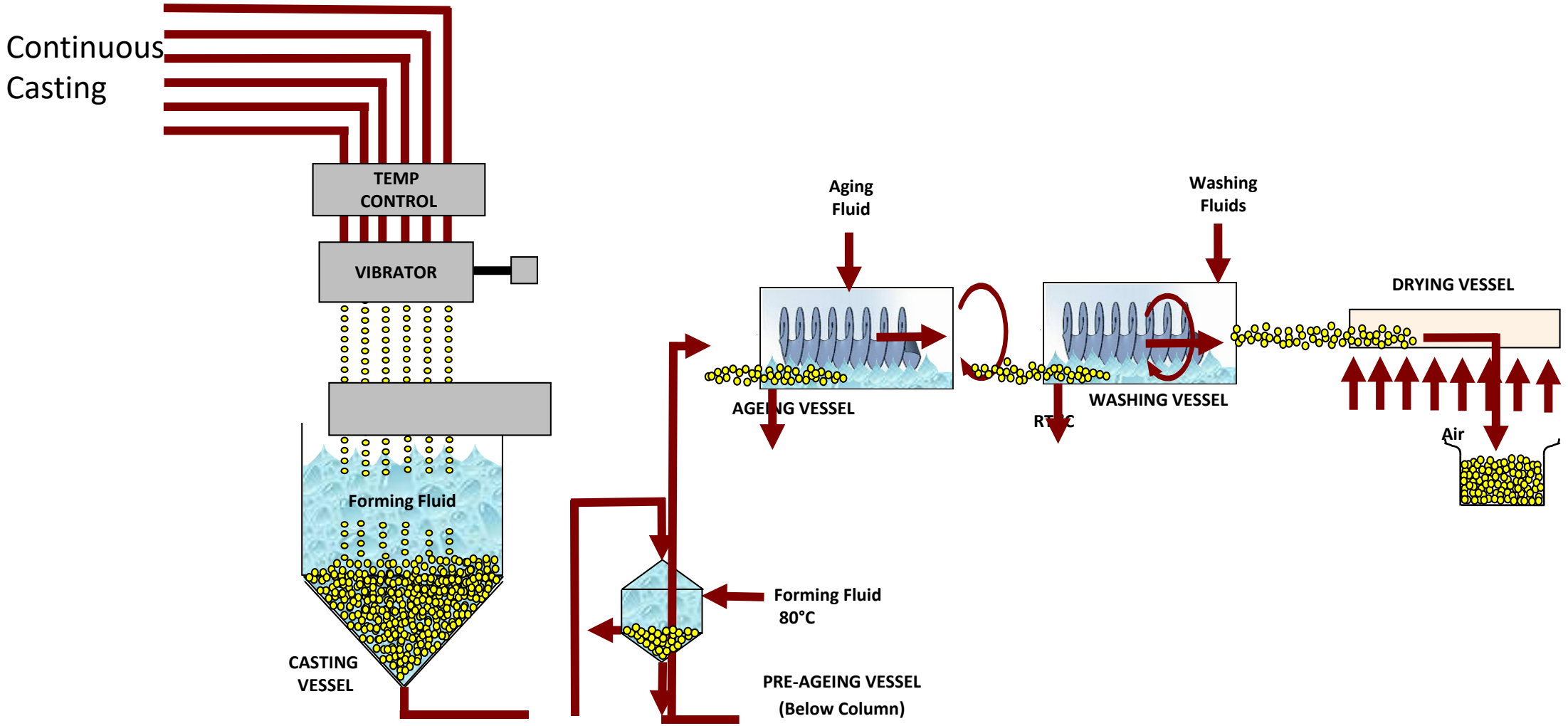
Kernel – Overall Process Description

- Gelation is used to produce uranium oxycarbide (UCO) kernels
  - The uranium powder for manufacturing is a maximum 19.55 wt% U-235 enriched U_3O_8 powder called High Assay Low Enriched Uranium (HALEU).
  - The kernels are produced using nuclear grade U_3O_8 powder or recovered U_3O_8 powder as feed material.
  - UCO kernels are dense sintered microspheres consisting of uranium dioxide (UO_2), uranium di-carbide (UC_2) as well as uranium carbide (UC) with an approximate ratio of C/U of 0.1 – 0.4 and a specified diameter of 425 µm.
- Aging, washing, and drying are process steps that solidify the spherical, cast kernels and remove impurities
- The calcining and sintering process steps convert the kernels first to UO_3 and then to UO_2 while producing the desired phase distribution of UC + UC_2
- Sieving, sorting, sampling and portioning removes the undersized and oversized kernels, removes the aspherical kernels, and separates them into batches that correspond to a lot

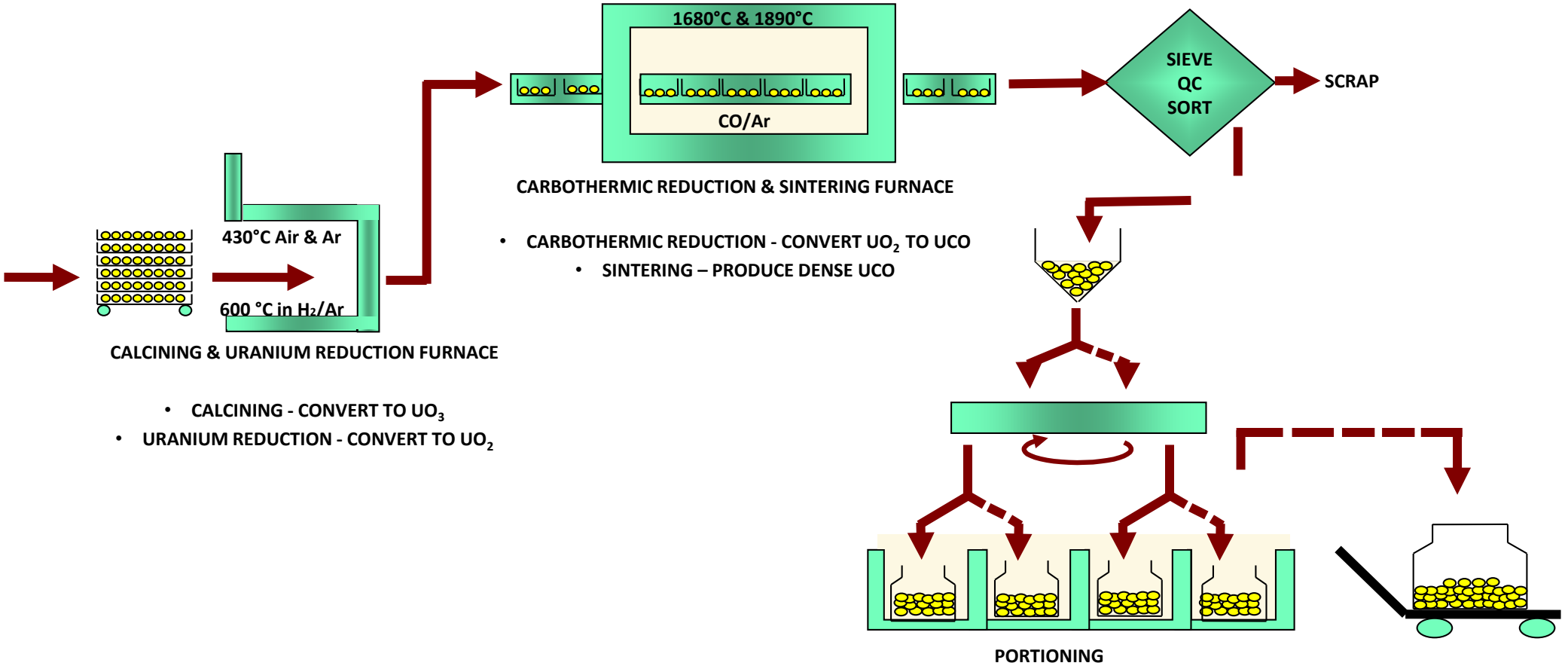
Solution Gelation – Dissolving and Casting Preparation



Aging, Washing, and Drying



Calcining and Sintering



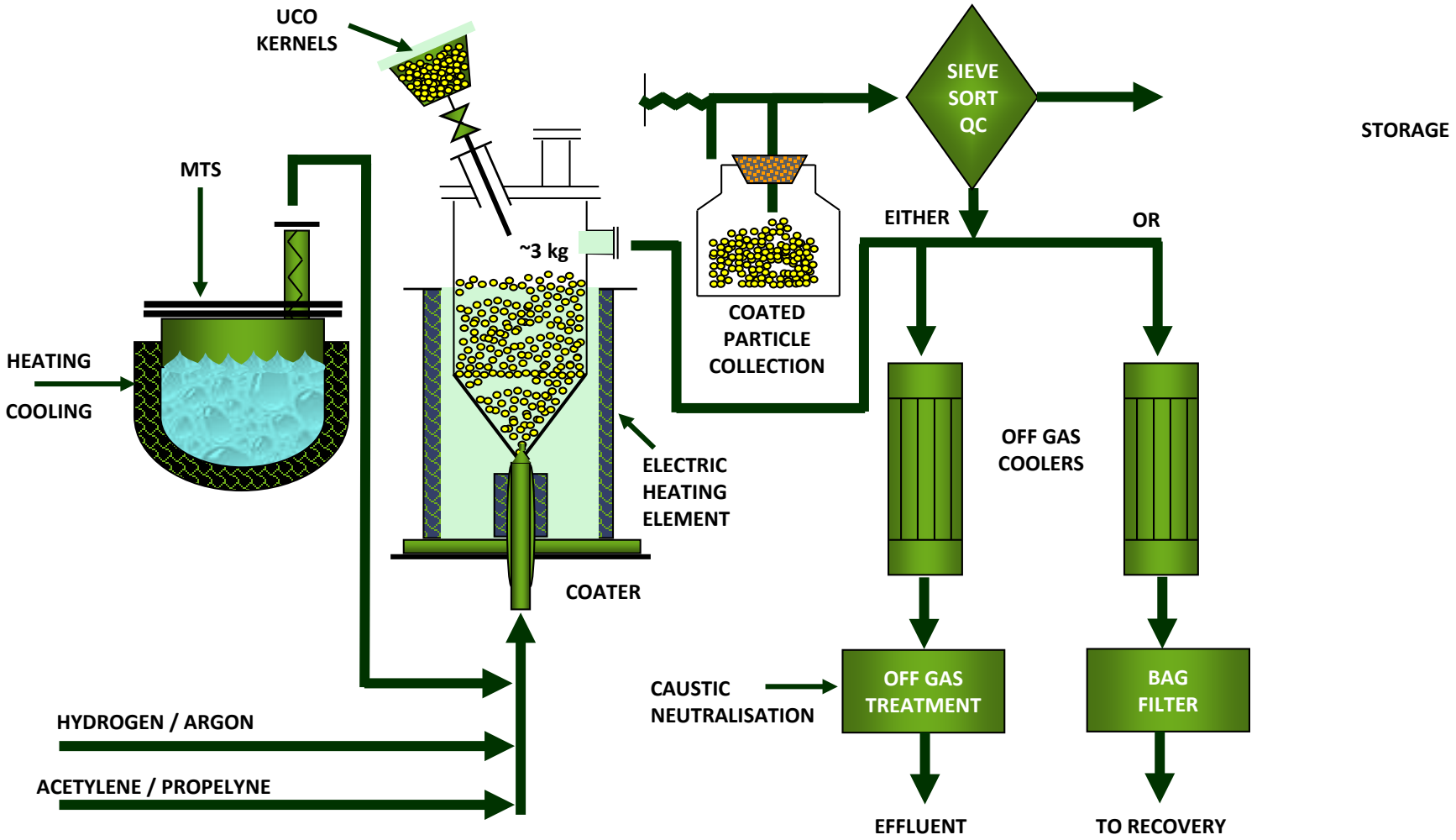
Kernel Coating

Particle Coating

- Chemical Vapor Deposition (CVD) is used for the coating of uranium oxycarbide (UCO) kernels with pyrolytic carbon and silicon carbide to produce tristructural isotropic (TRISO) coated particles

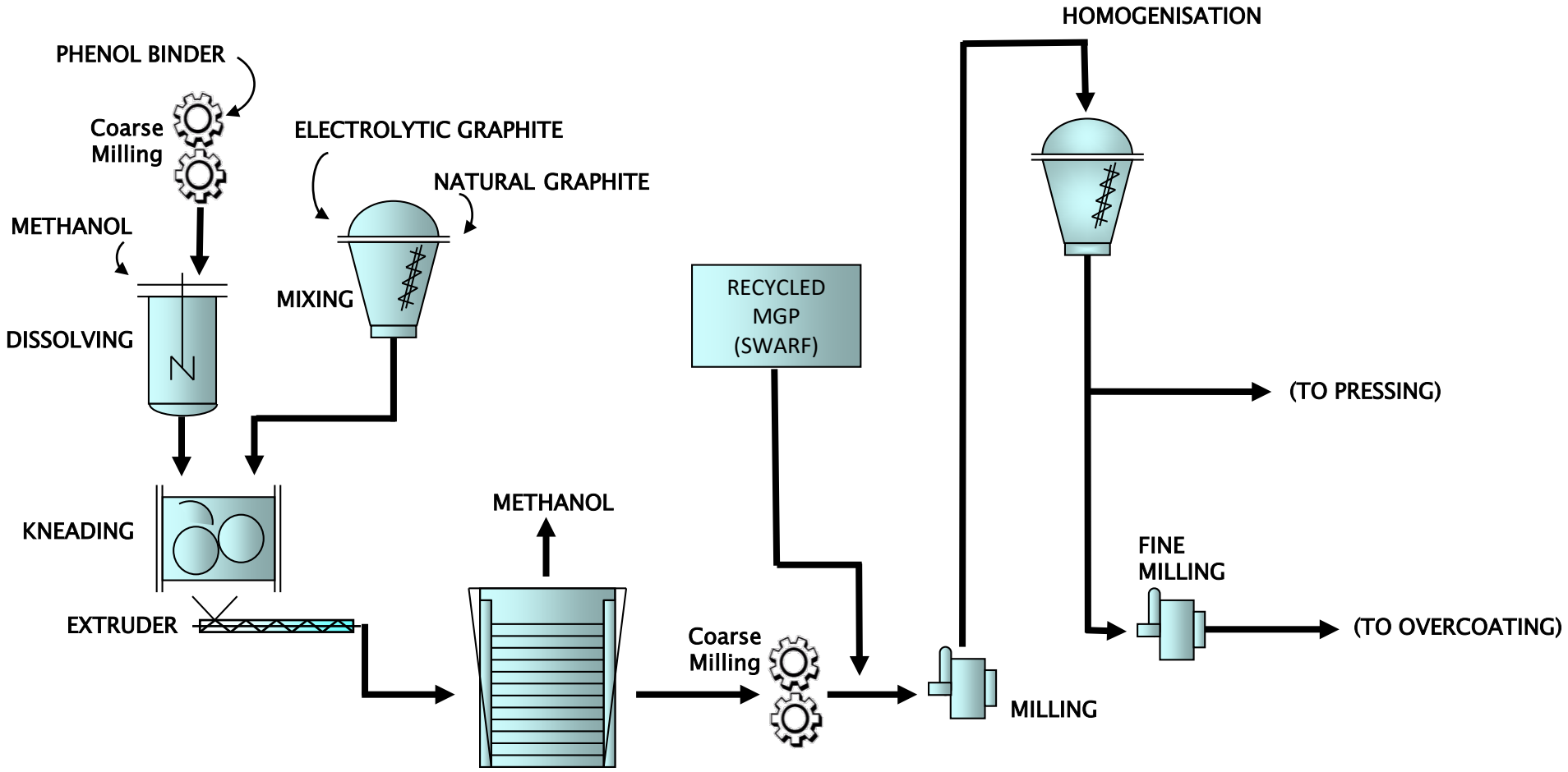
	Coating Gas: Carrier Gas
UCO Kernel	-
Porous Carbon Buffer Layer	C_2H_2 in Ar
IPyC Layer	C_3H_6/C_2H_2 in Ar
SiC Layer	MTS (Methyltrichlorosilane, CH_3Cl_3Si) in H_2
OPyC Layer	C_3H_6/C_2H_2 in Ar

Coated Particle Process

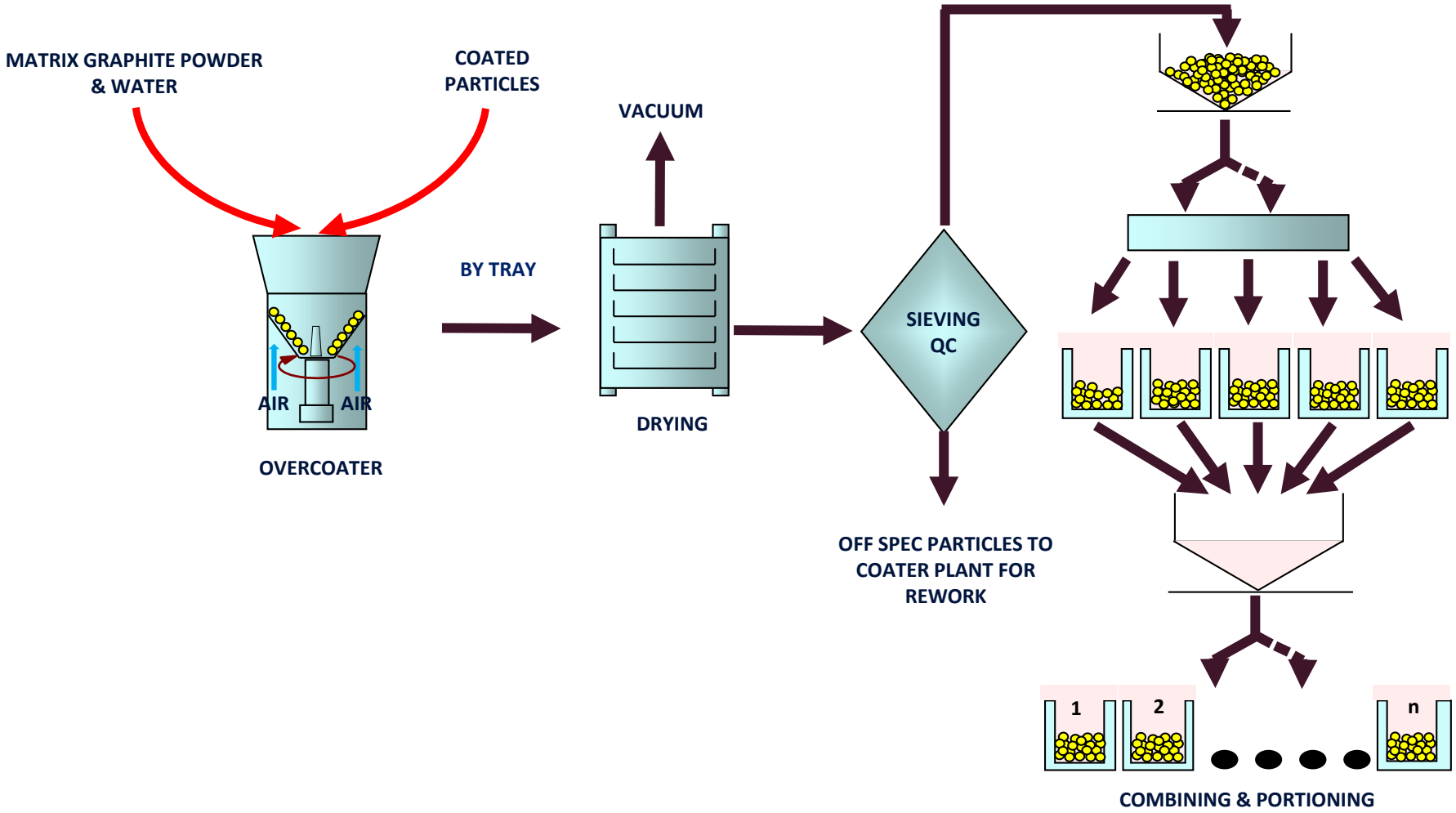


Pebble Manufacturing

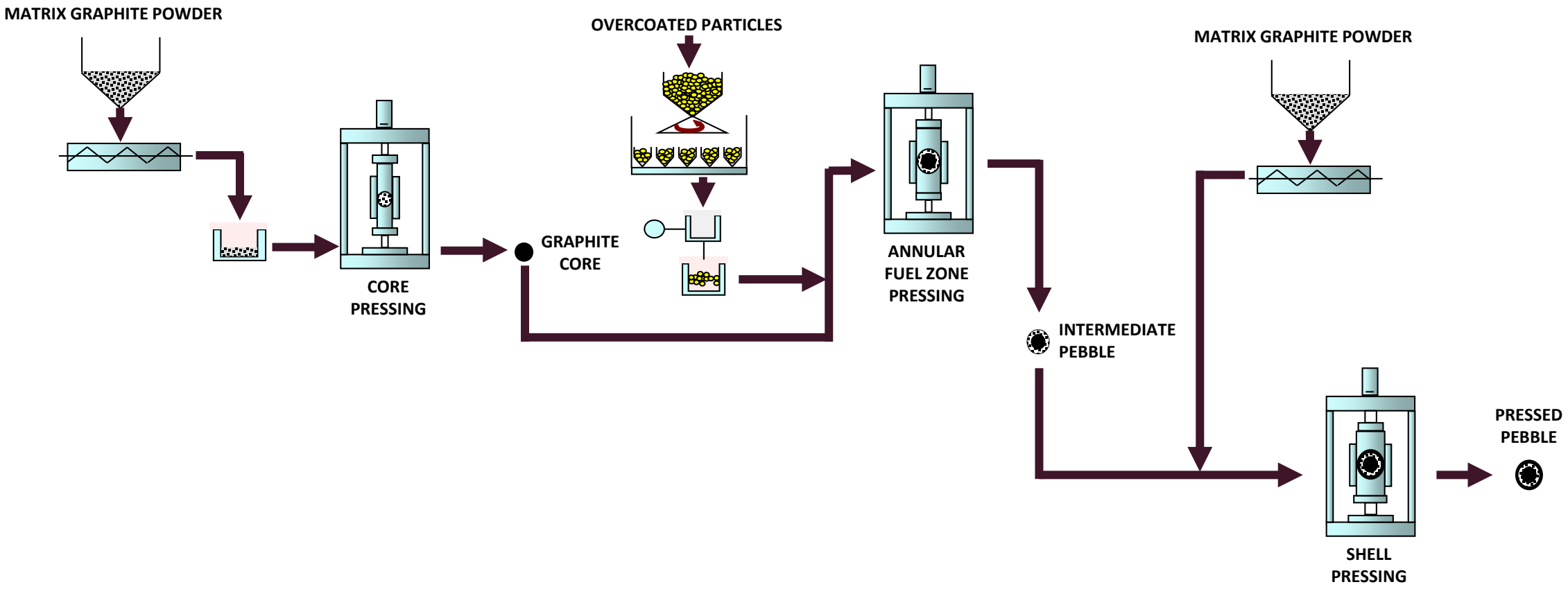
Matrix Graphite Powder Manufacturing



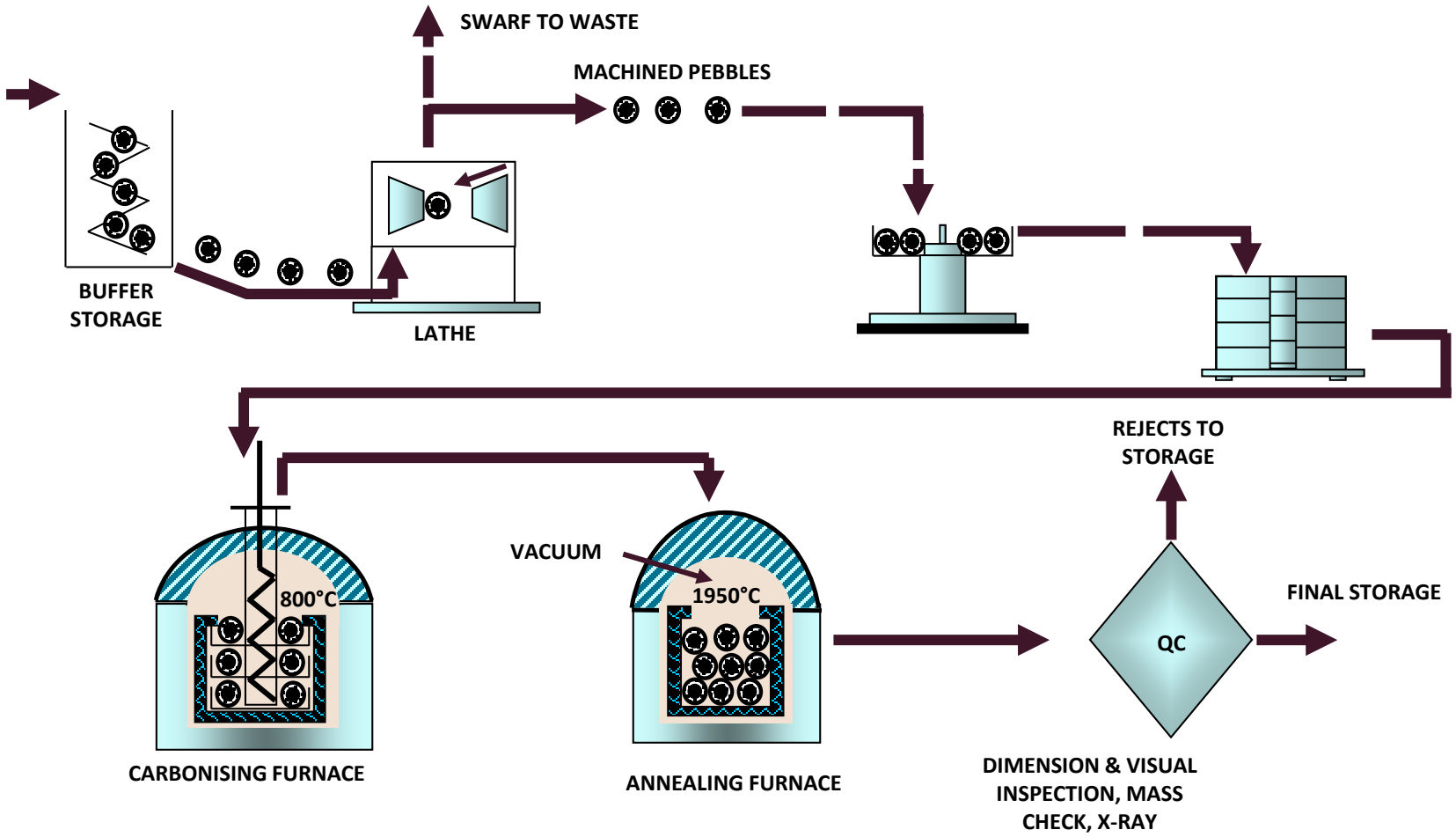
Pebble Facility – Overcoating, Drying and Portioning



Pebble Facility – Pebble Pressing



Pebble Facility – Machining



Fuel Specifications and Inspections

Specifications are established to guide product inspections and ensure product quality, customer defined expectations, and fuel performance. The specifications cover:

- Raw materials and consumables
- Intermediate product forms
  - Kernels
  - Kernel Coatings (TRISO particles)
- Matrix graphite powder product
- Final annular fuel pebbles

Waste Management

Waste Management – Overall Process Description

- The waste streams in this facility include liquid effluents, off-gases, or contaminated solids from the various steps in the fabrication process
- The effluents are either purified to be re-used or treated to the required specification to be released or sent for disposal
- Off-gases are treated to the required release specification before being released to the atmosphere. Some chemicals are recovered from off-gases prior to release, as required.
- The small quantity of contaminated solids are collected, repackaged and stored for later treatment or disposal
- Liquid effluents with potential for uranium contamination will be stored or processed in vessels with a critically safe geometry

Balance of Plant

Balance of Plant Systems

The balance of plant (BOP) systems are:

- Utility and services systems: gases, reagents, waters and power supply
- Heating ventilation air conditioning, fire, gas, and radiological protection systems
- Civil and structural: process areas, offices, change rooms, tanks
- General and support: communication systems, facility monitoring and security, decontamination, maintenance and support, emergency response

Balance of Plant Systems – Utilities and Services

Utility Gases:

- Acetylene – manifold cylinder pallet
- Ammonia – multiple cylinders
- Argon – bulk liquid argon system
- Carbon monoxide – cylinder supply
- Compressed air – a compressor unit with dryer and accumulator
- Hydrogen – multiple cylinders
- LPG – bulk LPG system
- Nitrogen – MCP
- Propylene – cylinder supply
- Steam – a boiler with condensate return system
- MTS – methyl trisilicate

Balance of Plant Systems – Utilities and Services

Utility liquid reagents :

- Aqueous ammonia solution
- Ammonium nitrate
- Aqueous nitric acid solution
- Isopropanol (IPA)
- Surfactant (SPAN 80) tetrahydrofurfuryl alcohol (THFA)
- Trichloroethylene (TCE)

Balance of Plant Systems – Utilities and Services

Utility solid reagents:

- Carbon black
- Dispersing agent (Tamol)
- Hexamethylenetetramine (HMTA)
- Polyvinyl alcohol (PVA)
- Ammonium hydroxide
- Triuranium octoxide
- Urea
- Caustic

The utility reagents are stored in the appropriate storage areas.

Balance of Plant Systems – Utilities and Services

Utility water includes:

- Chilled water – chiller unit
- Cooling water – cooling tower
- Demineralized water – demineralized water system
- Potable water – tie into the municipal supply
- Backup Cooling water – potable water supply
- Process water – recovered water or potable water
- Discharge water – municipal waste system

Balance of Plant Systems – HVAC

The functions of the Facility HVAC system/s are to:

- Provide sufficient space conditioning to the various areas within the facility
- Provide dynamic confinement in the building by means of pressure gradients between the various areas
- Capture and remove air-borne hazardous substances generated during operations
- Prevent the spreading of fires

The Facility HVAC System is comprised of:

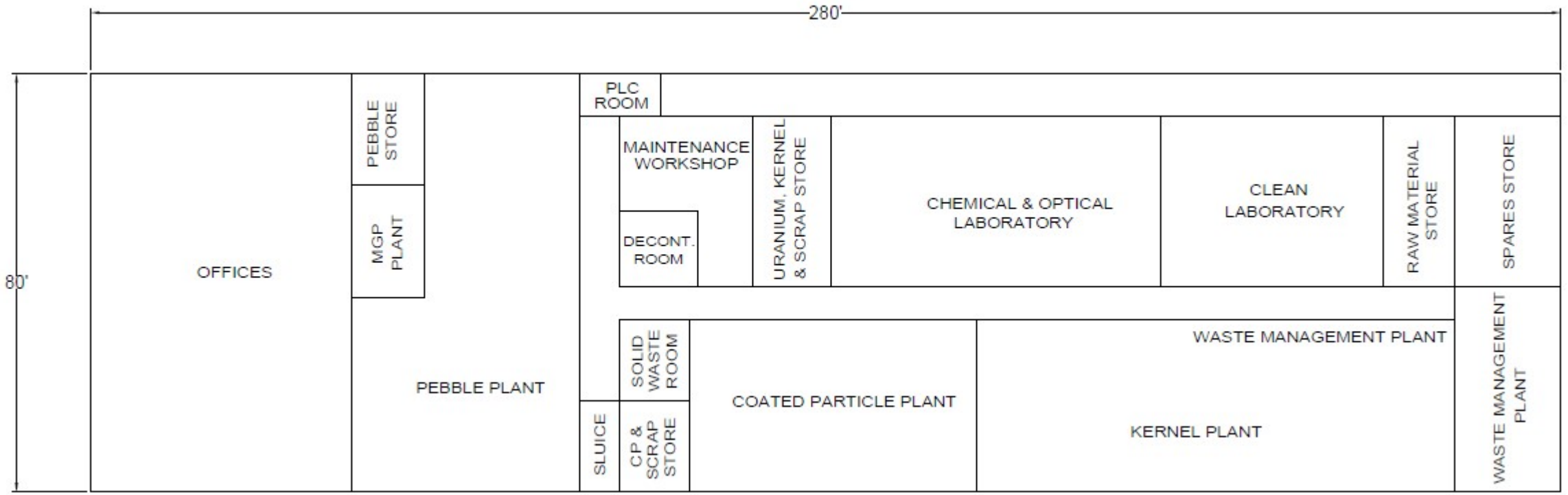
- Building HVAC (Room supply and extraction)
- Process ventilation
- Process off-gas

Balance of Plant Systems – Fire Protection System

The functions of the Fire Protection System are to:

- Detect fires at an early stage
- Suppress fires at an early stage by means of an inert gas system
- Prevent the spreading of fires
- Detect the build-up of flammable / explosive vapors at an early stage

Atlas Conceptual Layout



Licensing

Regulatory Approach

- Application prepared in compliance with 10 CFR 70, “Domestic Licensing of Special Nuclear Material” and 10 CFR 51, “Environmental Protection Regulations for Domestic Licensing and Related Regulatory Function”
  - Fuel Facility Environmental Report (ER) will leverage Hermes ER due to proximity of the two facilities
- The application will also address the following regulations:

10 CFR 20	**Standards for Protection Against Radiation**
10 CFR 21	Reporting Defects and Noncompliance
10 CFR 30	Rules of General Applicability to Domestic Licensing of Byproduct Material
10 CFR 40	Domestic Licensing of Source Material
10 CFR 73	Physical Protection of Plants and Materials
10 CFR 74	Material Control and Accounting of Special Nuclear Material
10 CFR 75	Safeguards on Nuclear Material

- Application will use guidance in NUREG-1520, “Standard Review Plan for Fuel Cycle Facilities License Application”
- ER will follow guidance in NUREG-1748, “Environmental Review Guidance for Licensing Actions Associated with NMSS Programs (NUREG-1748)”
  - Format consistent with Hermes ER
- Plan is to submit the application in two parts (ER first, then Part 70 and ISA Summary second), which will require an exemption

Regulatory Approach *(continued)*

- Other NUREGs that will be used to inform the application are:
  - NUREG-1140, “A Regulatory Analysis on Emergency Preparedness for Fuel Cycle and Other Radioactive Material Licenses"
  - NUREG-1513, “Integrated Safety Analysis Guidance Document”
  - NUREG-1601, “Chemical Process Safety at Fuel Cycle Facilities”
  - NUREG/CR-6410, “Nuclear Fuel Cycle Facility Accident Analysis Handbook”
- Application will be informed by Interim Staff Guidance:
  - FCSS-ISG-04, “Baseline Design Criteria”
  - FCSS-ISG-12, “Reportable Events per 10 CFR 70, Appendix A”
  - FCSS-ISG-14 , “Acute Uranium Exposure Hazards for Workers”
  - FCSS-ISG-15, “Natural Phenomena Hazards for Fuel Cycle Facilities”

Outline of Fuel Facility License Application

Chapter	Title	Content
1	General Information	Facility and process overview, institutional information, site overview
1.1	Facility and Process Overview	Facility layout description, process overview, site overview, descriptive summary of licensed material
1.2	Institutional Information	Corporate identity and ownership, financial qualifications, characteristics of the material, authorized uses, special exemptions or special authorizations, protection of SGI, security of classified info, license period
1.3	Site Description	Geography, demographics, meteorology, hydrology, geology
2	Organization and Administration	Facility organization chart, key management functions, administrative policies and procedures, qualifications of key positions
3	Integrated Safety Analysis and Integrated Safety Analysis Summary	Process safety information, ISA Team, ISA summary (stand alone document)
4	Radiation Protection	Radiation protection programs, ALARA Program, radiological organization and qualifications, procedures, radiation training, respiratory protection, surveys and monitoring.

Outline of Fuel Facility License Application *(continued)*

Chapter	Topic	Content
5	Nuclear Criticality Safety	Management measures for criticality, criticality monitoring, criticality analysis methodology, double contingency
6	Chemical Safety	Chemical information, chemical hazards analysis
7	Fire Safety	Administrative controls, fire protection features and system, fire fighting capability, fire hazards analysis
8	Emergency Management	Emergency planning
9	Environmental Protection	Effluent monitoring, environmental surveillance, permits, design basis
10	Decommissioning	Management, overall plan, recordkeeping, financial assurance
11	Management Measures	Quality Assurance, configuration management, maintenance, training/qualification, procedures, audits and assessments, Incident Investigations, records management
12	Material Control and Accounting	Management, physical inventory, recordkeeping
13	Physical Protection	Physical protection, training and qualification, safeguards contingency

Integrated Safety Analysis Regulatory Approach

- Integrated Safety Analysis (10 CFR 70.62) will be focused on:
  - Radiological Safety
  - Fire Safety
  - Nuclear Criticality
  - Chemical Safety
- Each Step of the Manufacturing Process (and material receipt and fuel storage) will be assessed:
  - Radiological Safety is addressed by Items Relied on for Safety (IROFS), which in turn are supported by management measures
  - Criticality addressed by geometry, neutron absorbers, mass control, alarms, double contingency
  - Fire protection addressed by separation, barriers, detection, alarm, and suppression as appropriate
  - Chemical safety addressed by engineering and administrative controls and defense in depth


QUESTIONS?