X-energy: Nuclear Data Needs for HTGR Systems

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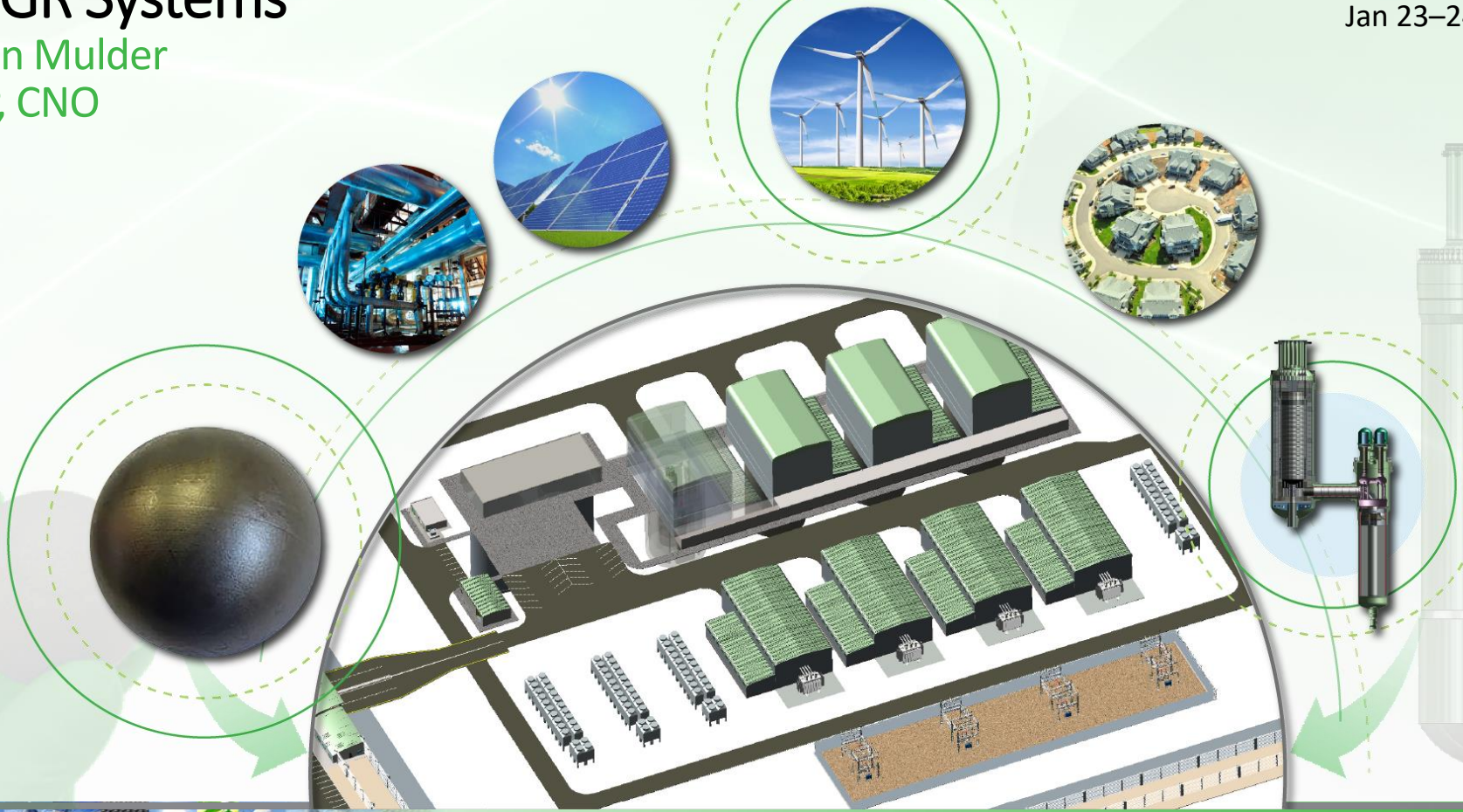
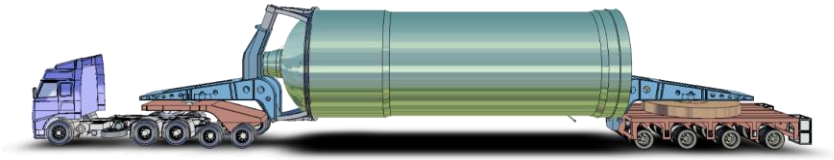


Nuclear Energy. Reimagined.

Pebble Bed High Temperature Reactor

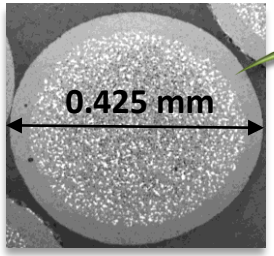
Plant features / attributes include:

- Using proven UCO TRISO Fuel in graphite pebbles
- Passive safety features - Cannot melt-down
- Operated without needed water source
- Load-following to 100% - 40% power within 12 minutes (5% per minute)
- Online fueling; resilient on-site fuel storage
- Requires less time to construct (2.5 - 4 years)
- Road transportable for diverse geographic areas

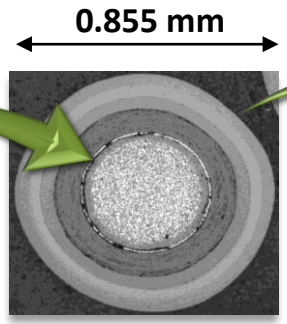


Thermal Output	Electric Output	Steam Pressure	Steam Temperature
200MWth	~75MWe	16.5MPa	565°C

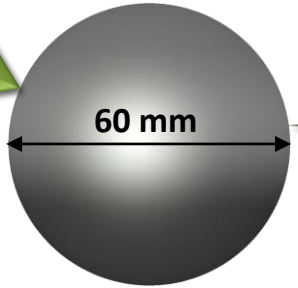
UCO TRISO Particle Pebble Fuel Elements



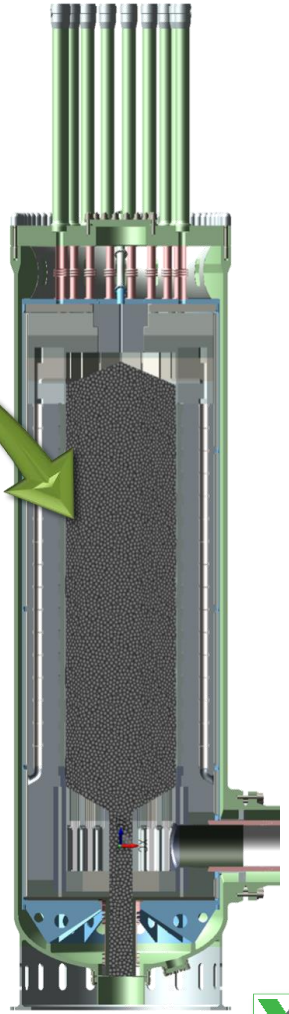
Optimized UCO kernel



≈ 20 000 TRISO coated particles in a pebble

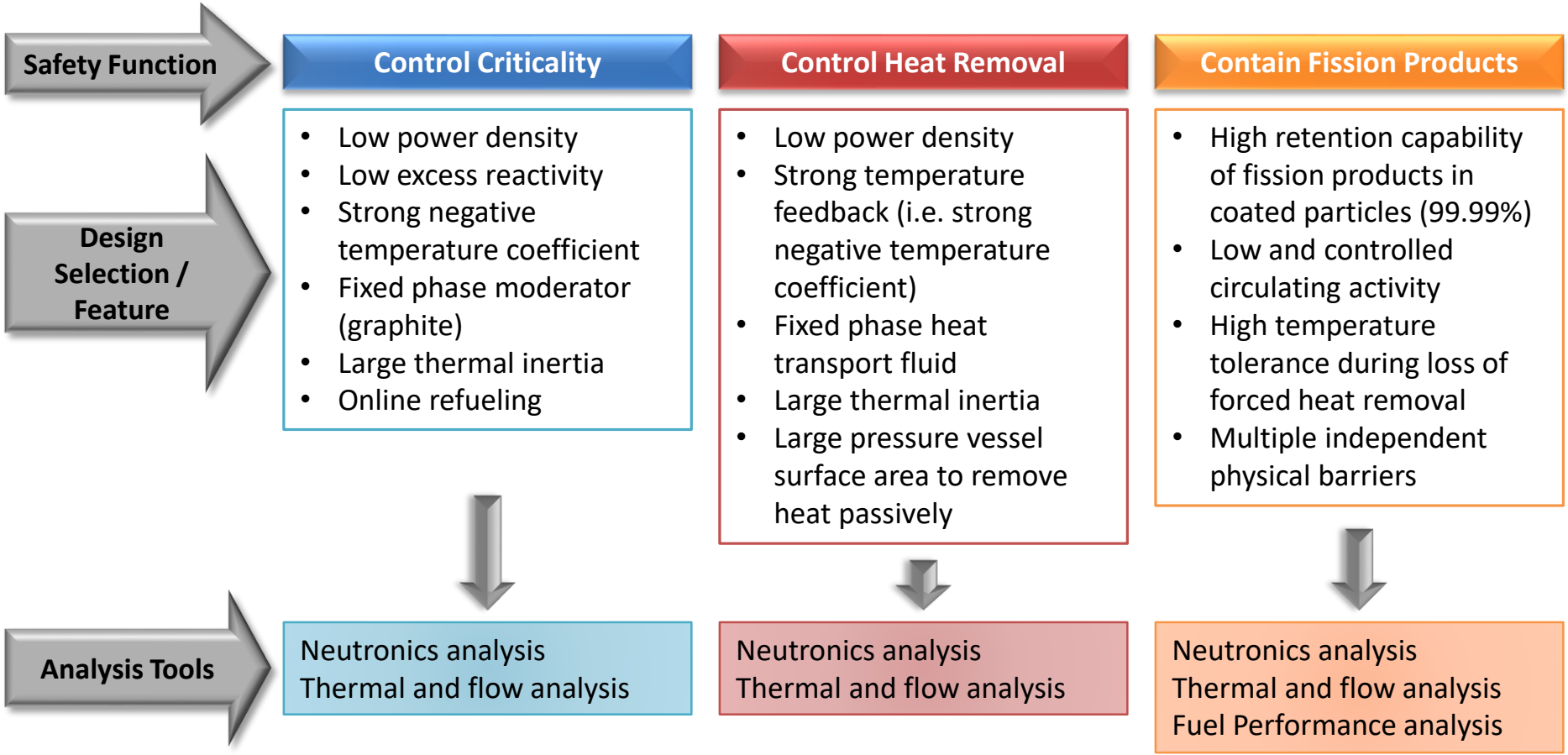


≈220,000 pebbles in the core



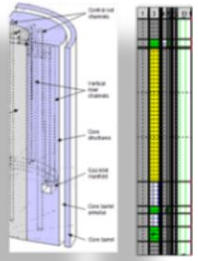
Primary safety goal is to ensure that fission products are retained within the TRISO coated fuel particles

Design Safety Basis



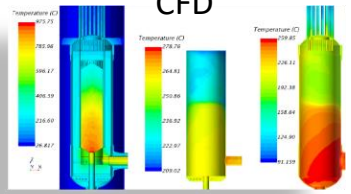
Reactor Integrated Design Process

Initial assumptions & requirements
- Power level
- Fuel cycle
- Power density
- Enrichment
- HM loading



Neutronic data

CFD



Initial Assumptions & Inputs

Step 1: Initial Core Design

Compli es with require-ments

Yes

Step 2: Reactor geometry design (core structure layout)

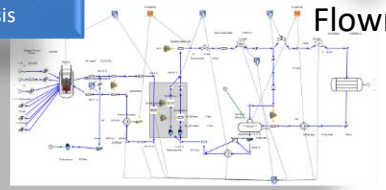
Step 3: Reactor Thermal & gas dynamic design optimization

Complies with require-ments

Yes

Step 4: Primary & secondary loop Analysis

Flownex



Step 5: Source term analysis

Complies with require-ments

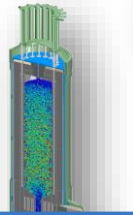
No

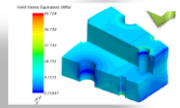
Update Initial assumptions

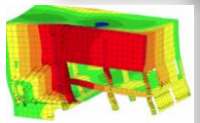
Update Initial assumptions

No

No







Yes

Step 6: DEM Pebble dynamics

Step 7: Structural Design (FEA)

Step 8: Seismic Analysis

Next Iteration

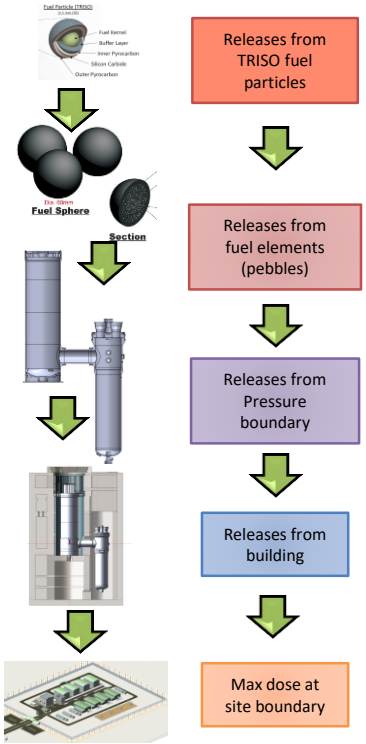
Neutronics Codes

- Mulit-scale, multi-physics design analyses to date have been performed using legacy pebble bed design codes – VSOP (Steady state), TOTMOS (Reactivity Control and Shutdown Systems) and MGT (Transient)

- These codes have a longstanding pedigree and have been used to design 3 operating reactors (AVR, THTR and HTR-10) as well as the HTR-PM that is nearing construction completion

Source Term Calculation

Source Term Path



Element / Isotope	Form / State	Mechanism	Physical Phenomena	Methods / Software Codes
Iodine Silver Strontium Cesium …	Gaseous FPs Metallic FPs	- Release from TRISO particles into matrix graphite - Activation of impurities	Temperature, irradiation time, fast fluence, burnup, particle defects, contamination	VSOP MGT **SCALE, PARCS, OREGIN** FLOWNEX XS-Term STAR-CCM+
Iodine, Silver Strontium Cesium Graphite dust	Gaseous FPs Metallic FPs Dust Particles	- Diffusion from pebble into the helium stream - Activation of impurities	Temperature, irradiation time, fast fluence, burnup, contamination	VSOP, MGT **SCALE, PARCS, OREGIN** FLOWNEX XS-Term STAR-CCM+
Iodine, Silver Strontium, Cesium Graphite dust Metallic dust	Gaseous FPs Metallic FPs Dust Particles	- Leakage from HPB into building and structures - Activation of impurities	Instrumentation line failure, small & large pipe breaks, plate-out, liftoff	**ORIGEN** XS-Term
Iodine, Silver Strontium, Cesium Graphite dust Metallic dust	Gaseous FPs Metallic FPs Dust Particles	- Transport throughout building to the environment	Plate-out, liftoff	XS-Term **MELCOR**
Iodine, Silver Strontium, Cesium Graphite dust Metallic dust	Gaseous FPs Metallic FPs Dust Particles	- Atmospheric dispersion - Ingestion	Postulates	XS-Term STAR-CCM+ ?

DOE Codes

Summary

- Core design work – i.e. coupled neutronics and thermofluidic calculations at X-energy is performed deterministically by means of Diffusion and Transport methodologies, as well stochastically by high fidelity codes, such as MCNP, coupled to ORIGEN and other codes
- Spectrum calculations for the diffusion codes are based on the GAM-I and the THERMOS codes respectively, needing fast, epithermal and thermal data libraries
- These respective nuclear libraries are extracted from basic nuclear data sets
- The GAM-I library presented in 68 energy groups ranges from 10MeV to 0.414eV. In its current form, it contains 181 isotopes
- The THERMOS library presented in 30 energy groups, ranges between 0 to 2.05eV
- The absorber elements are similar to those in the GAM-library
- The scattering nuclide kernels are prepared in accordance with to the particular application for different scattering laws at the associated temperatures. The basic thermal source library is given in 96 energy groups in the group structure of the THERMALIZATION spectrum code (a precursor of GATHER)
- Condensing of the THERMALIZATION library to a THERMOS library is based on a specific thermal neutron energy spectrum being adequate for the reactor and fuel elements under consideration. An auxiliary allows to modify the THERMALIZATION library
- Of particular note it is mentioned that several scattering matrices are presented of the same nuclide, such as graphite, oxygen, hydrogen, beryllium, etc. for different temperatures
- Neutron streaming behavior is considered statistically by means of a variety of corrections (eg. Lieberoth and Stojadinović, adapted Behrens, etc.)

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