

Proposed \$1B Nuclear Power Automated Site Construction Development Fund

By ChatGPT 5.6

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What is Nuclear Power Site-Construction Automation?

Prompt to AI: Summarize the proposed China-based nuclear power site-construction automation concept in roughly 700 words. The program should develop a common family of construction machines for two standardized Chinese reference plants: (1) an HTR-PM/HTR-PM600-type high-temperature gas-cooled plant and (2) a Hualong One/HPR1000-class pressurized-water reactor (PWR).

Source material

Climate Moonshot Business Plan

https://www.ma2life.org/g/Decarbonization_Lab_Biz_Plan.pdf

(PDF)

<https://drive.google.com/drive/folders/1EMb-Tqw49ewj16UeGhR7UOc9HY6POpKC>

(MS Word)

Low-Cost Nuclear Power [Video #11]

<https://www.youtube.com/watch?v=AIlbovU67wI>

Automated Nuclear Power Construction [Video #12]

<https://www.youtube.com/watch?v=af00cy1l7Qo>

How to Make \$10 Trillion Dollars [Video #13]

<https://www.youtube.com/watch?v=4gqmKGV1h5Y>

Chinese PWR reference and recent construction automation

https://en.cgnpc.com.cn/encgn/pressReleases/2026-07/21/content_44c301fbe6d744c3b880896edc8c5442.shtml

HTR-PM Nuclear Reactor (Wikipedia)

<https://en.wikipedia.org/wiki/HTR-PM>

HPR1000 ("Hualong One") Nuclear Reactor (Wikipedia)

https://en.wikipedia.org/wiki/Hualong_One

Response From AI:

The proposed fund would develop custom machines, standardized interfaces, and digital systems that automate repetitive site-construction work for two Chinese nuclear reference plants. The HTR-PM track would use a modular pebble-bed high-temperature gas-cooled reactor architecture derived from the commercially operating Shidao Bay HTR-PM and the larger multi-module HTR-PM600 concept. The PWR track would use a Hualong One/HPR1000-class plant representative of the standardized Generation III pressurized-water reactors that China is now building in series. The program would not redesign reactor physics, fuel, or the nuclear steam-supply system. It would redesign how approved plant structures and components are constructed, moved, positioned, inspected, and documented at the site.

The economic hypothesis is that a common construction platform can attack costs shared by both reactor types: excavation and earthworks, rock finishing, reinforced concrete, steel liners and structural modules, material movement, heavy lifting, fit-up, welding assistance, inspection, cable and pipe support installation, metrology, rework, and schedule delay. The same core machines should be designed to accept reactor-specific tools and fixtures. A machine fleet that moves from project to project can improve through repetition, reduce craft variability, support 24/7 bounded operation, and generate comparable cost, schedule, safety, and quality data across many plants.

The two reactor tracks require different civil architectures. The HTR-PM concept in the Climate Moonshot Business Plan uses repeated deep, lined cylindrical excavations, rail-mounted gantries, and factory-built support modules. A Hualong One-class PWR instead requires a large nuclear island, basemat, containment structure, steel liner, equipment compartments, major embedded items, and heavy installation of the reactor pressure vessel, steam generators, pressurizer, pumps, piping, and structural modules. The fund therefore should maximize common machinery while allowing different end-effectors, work envelopes, lifting systems, formwork, and sequencing for each reference plant. Figures in this document primarily illustrate the HTR-PM track; the PWR track requires its own full-scale mockups and test articles.



Figure 1: The HTR-PM demonstration plant, one of the two China reference tracks.

The five-year effort would be a construction-equipment and construction-process development program. It would design, prototype, test, and debug machines at a shared non-nuclear pilot site in China or elsewhere. Human-supervised automation is the appropriate initial objective: machines execute bounded tasks automatically while qualified operators authorize starts, pause work,

intervene, and recover from faults. The PWR track is particularly valuable because China already has a large Hualong One supply chain and is deploying modularization, mechanization, automation, digitalization, intelligent construction systems, automatic welding, and construction robots. The fund should build on those practices rather than pretend it is starting from zero.

A successful program would deliver two frozen reference construction models, a common machine architecture, reactor-specific tooling packages, full-scale or near-full-scale prototypes, representative HTR-PM and PWR civil test articles, heavy transport and component-placement demonstrations, and an auditable digital quality record. It would independently measure the site-construction cost and schedule effects for both designs, including first-of-a-kind and repeated-build cases. It would also quantify a potential HTR-PM siting/transmission advantage without assuming that Chinese regulators will automatically allow closer siting. The output is evidence for a first licensed deployment decision, not a promise of a particular electricity price.

Key boundary of the fund

- Included: China-specific construction-system design; HTR-PM and PWR reference construction models; non-nuclear prototypes; civil and structural test articles; heavy equipment; site logistics; digital engineering; metrology; quality records; pilot demonstrations; cost/schedule models; and licensing-support studies.
- Excluded: nuclear fuel qualification; reactor physics R&D; redesign of safety functions merely to simplify construction; commercial plant construction; electricity generation; and ownership or operation of an HTR-PM or PWR plant.
- Conditional: controlled access to HTR-PM and Hualong One/HPR1000 design data, Chinese codes and standards, supplier information, and regulator engagement. If proprietary design access is incomplete, use functionally representative non-nuclear mockups while preserving the dual-reference construction mission.

HTR-PM + PWR Construction Automation - \$1B Fund

Prompt to AI: A five-year fund has \$1 billion to develop custom machines and systems that automate site construction in China for both an HTR-PM/HTR-PM600-type plant and a Hualong One/HPR1000-class PWR. How should the money be allocated, what should the program deliver, and what should it explicitly not promise?

Response From AI:

The recommended interpretation is a dual-reference design-and-demonstration program, not the construction budget for nuclear plants. All amounts are preliminary planning estimates in constant 2026 dollars. The baseline technical program is \$800 million, with a centrally controlled \$200 million reserve. The program deliberately avoids splitting the money into two independent \$500 million efforts. Instead, it develops a common machine platform first, then funds HTR-PM-specific and PWR-specific tooling and test articles only where plant geometry or nuclear construction sequence truly differs. This creates a direct competition: for each task, measure whether one common machine, two variants, or conventional Chinese construction is cheapest and most reliable.

Work package	Budget	Share	Principal five-year deliverable
1. Dual-reference plant, site, and construction-system design	\$90M	9.0%	Controlled HTR-PM and Hualong One construction reference models, common interfaces, reactor-specific tooling envelopes, quantities, sequences, and machine procurement packages.
2. Excavation, earthworks, and precision rock-cutting machines	\$95M	9.5%	Full-scale or near-full-scale prototypes for HTR-PM deep excavation and PWR bulk excavation/foundation preparation, using common controls and interchangeable tools where practical.
3. Material handling, spoil removal, and machine exchange	\$55M	5.5%	Integrated material-flow and machine-exchange systems that keep both HTR-PM and PWR construction fronts supplied without waiting on haulage, staging, or maintenance.
4. Heavy lift, gantry, crane, rail, and positioning systems	\$95M	9.5%	Prototype heavy-handling systems with standardized lifting interfaces and reactor-specific fixtures for repeated HTR-PM cells and large PWR nuclear-island components/modules.
5. Concrete, rebar, formwork, steel-liner, and structural automation	\$150M	15.0%	Automated structural construction for HTR-PM lined excavations and PWR basemat/containment work, including rebar, embedments, concrete, steel liners, inspection, and digital records.
6. Heavy-module transport and site-logistics system	\$80M	8.0%	Reusable transport and staging systems for factory-to-site movement of HTR-PM modules and PWR structural/mechanical modules, with standardized site handoff interfaces.
7. Reactor-island and support-module installation automation	\$85M	8.5%	Mockups and tools to transport, position, align, connect, inspect, and repeatedly install major HTR-PM and PWR components without nuclear material.

Work package	Budget	Share	Principal five-year deliverable
8. Digital twin, autonomy, metrology, and nuclear QA data thread	\$65M	6.5%	One integrated planning, control, metrology, configuration, quality, and auditable as-built data thread supporting both reactor construction tracks.
9. Integrated dual-track pilot site and end-to-end demonstration	\$55M	5.5%	Shared non-nuclear pilot with distinct HTR-PM and PWR test zones where the common machine fleet and reactor-specific tooling operate end to end and produce independent evidence.
10. Program management, nuclear QA, China licensing support, and independent review	\$30M	3.0%	Owner-side program office controlling the common platform, two reference designs, contracts, interfaces, cost, schedule, safety, quality, data rights, independent review, and transition.
11. Central contingency and risk reserve	\$200M	20.0%	Funds released only for documented technical, integration, supplier, site, China-regulatory, or schedule risks across either reactor track.

Suggested five-year funding profile

Year	Technical work	Reserve	Total	Primary emphasis
Year 1	\$110M	\$20M	\$130M	Freeze the two China reference construction models; map common versus reactor-specific tasks; design-data strategy; economics; safety/licensing basis.
Year 2	\$160M	\$30M	\$190M	Preliminary machine design, competing concepts, HTR-PM and PWR civil mockup design, component tests, pilot-site design.
Year 3	\$210M	\$40M	\$250M	Detailed design, prototype fabrication, common controls/digital thread, pilot civil work, reactor-specific tooling.
Year 4	\$210M	\$60M	\$270M	Peak fabrication and full-scale demonstrations: HTR-PM excavation/lining; PWR basemat/containment/liner; heavy transport and installation.
Year 5	\$110M	\$50M	\$160M	Repeated dual-track campaigns, reliability growth, independent cost/schedule audit, China deployment and Phase II packages.
Total	\$800M	\$200M	\$1.000B	Reserve remains under sponsor control and may remain unspent.

Program-level success criteria

- Two controlled China reference construction models - one HTR-PM/HTR-PM600-type and one Hualong One/HPR1000-class PWR - with interfaces, quantities, tolerances, sequences, and licensing assumptions.
- Full-scale or near-full-scale non-nuclear civil test articles representing the hardest HTR-PM underground work and the hardest PWR basemat/containment/steel-liner work.
- A common prototype fleet for excavation, material flow, heavy handling, rebar, concrete, structural installation, transport, metrology, autonomy, and digital QA, with reactor-specific tooling where required.
- Repeated HTR-PM and PWR end-to-end demonstrations with measured labor, machine cycle time, availability, quality, rework, safety, cost, and schedule.

- Auditable as-built data threads for both reference plants linking design to materials, machine logs, surveys, inspections, NDE, nonconformances, and acceptance.
- Independent bottom-up estimates of site-construction \$/W, total plant CAPEX impact, build time, plant-gate LCOE impact, and delivered-electricity impact under multiple transmission-distance scenarios.

What the fund would not accomplish

- It would not build or license an operating nuclear power plant.
- It would not demonstrate nuclear fuel, reactor operation, helium-system operation, PWR primary-system operation, or electricity generation.
- It would not assume the HTR-PM underground concept or the current Hualong One construction sequence is optimal; competing civil and modularization concepts must be tested.
- It would not guarantee a specific overnight capital cost, construction duration, siting distance, transmission cost, or electricity price.
- It would not relax nuclear safety classification, QA, inspection, or regulatory requirements to make automation easier; the target is high automation under qualified human supervision.

Development Phases

Prompt to AI: For each dual-reference budget item, identify the development phases, approximate cost, deliverable, and major decision gates. Distinguish common machinery from HTR-PM-specific and PWR-specific tooling.

Response From AI:

The phases below overlap across the five-year program. The key discipline is to freeze two reference construction models early enough that machinery is designed against real quantities, loads, tolerances, Chinese codes, and work sequences. Common machinery should be favored when it reduces lifecycle cost; reactor-specific tooling should be funded only when geometry, safety classification, or sequence makes commonality uneconomic or unsafe.

Common stage	Timing	Purpose
A. Requirements and feasibility	Months 0-12	Freeze the HTR-PM and PWR construction reference models, compare alternatives, secure design data, and test physical/economic assumptions.
B. Preliminary design and risk reduction	Months 6-24	Down-select common versus reactor-specific concepts; test critical civil, structural, controls, logistics, and China-code risks.
C. Detailed design and procurement	Months 18-36	Produce controlled drawings, software baselines, supplier packages, mockups, long-lead procurements, and dual-track pilot plans.
D. Fabrication and qualification	Months 24-44	Build prototypes and prove loads, precision, endurance, compatibility, safe failure behavior, and repeatability on representative HTR-PM/PWR tasks.
E. Integrated pilot demonstration	Months 36-56	Operate systems in both test zones and collect independent performance, safety, quality, cost, and schedule evidence.
F. Reliability growth and handoff	Months 48-60	Correct deficiencies, freeze replicable designs, and prepare separate first-site packages for HTR-PM and PWR deployment in China.

1. Dual-reference plant, site, and construction-system design - \$90 million

Controlled HTR-PM and Hualong One construction reference models, common interfaces, reactor-specific tooling envelopes, quantities, sequences, and machine procurement packages.

Subphase	Principal activity and deliverable	Cost
1A	China reference requirements, design-data access, and licensing strategy	\$15M
1B	Site envelopes, civil quantities, geotechnical assumptions, and temporary works for both reference plants	\$15M
1C	Design-for-automation, modularization, common interfaces, and construction sequence	\$20M
1D	HTR-PM-specific underground construction cell and machine-interface design	\$15M
1E	PWR-specific basemat, containment, steel-liner, embedment, and nuclear-island	\$15M

Subphase	Principal activity and deliverable	Cost
	construction design	
1F	Comparative cost/schedule/siting model and final machine procurement package	\$10M

Decision gate

The largest fabrication or pilot commitment remains conditional until requirements, interfaces, safety, quality, cost, schedule, and independent preliminary-design review are complete.

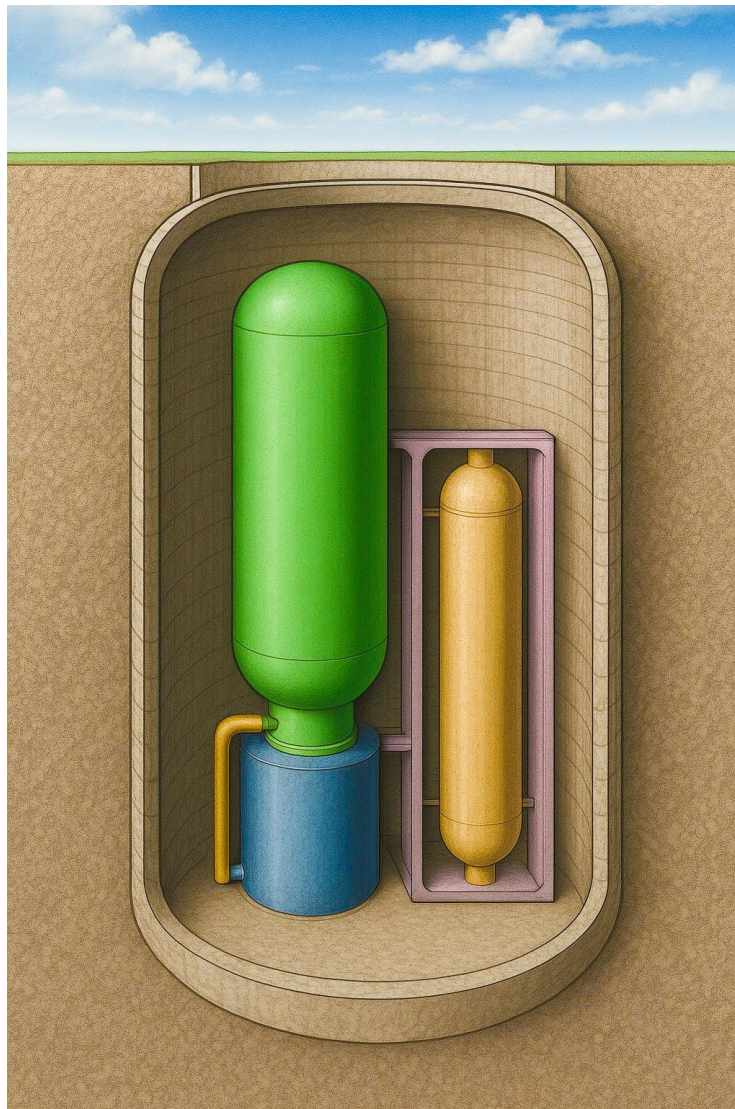


Figure 2. HTR-PM-track conceptual underground placement of a reactor vessel and heat exchanger.
Source: Climate Moonshot Business Plan; concept by Glenn Weinreb.

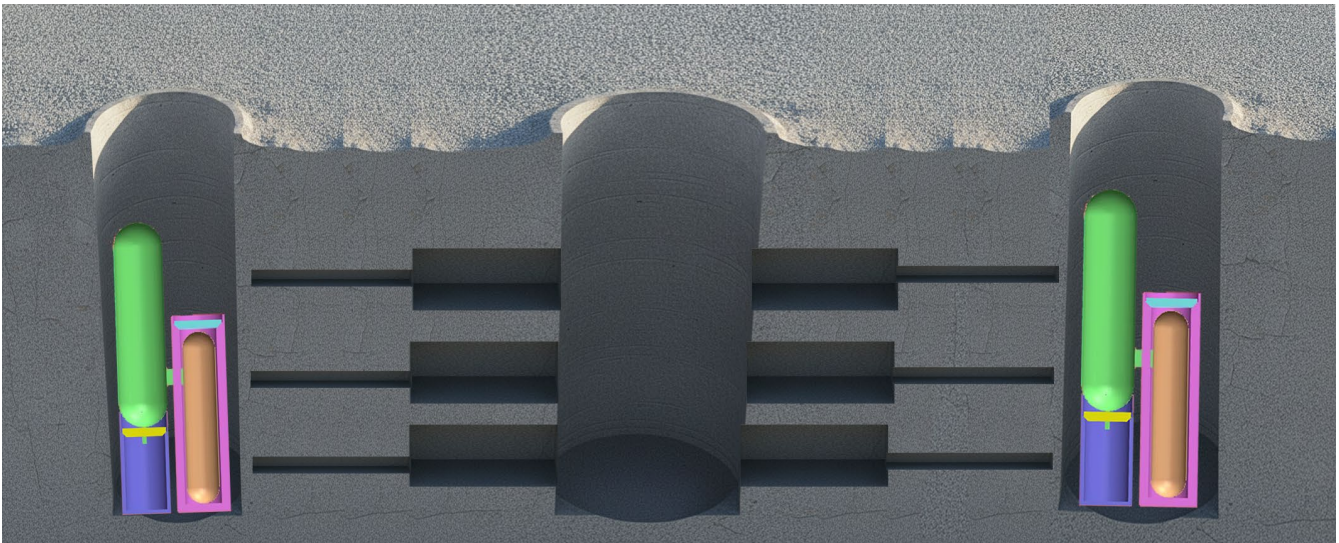


Figure 3. HTR-PM-track repeated excavations for reactor vessels and support equipment.
Source: Climate Moonshot Business Plan; concept by Glenn Weinreb.

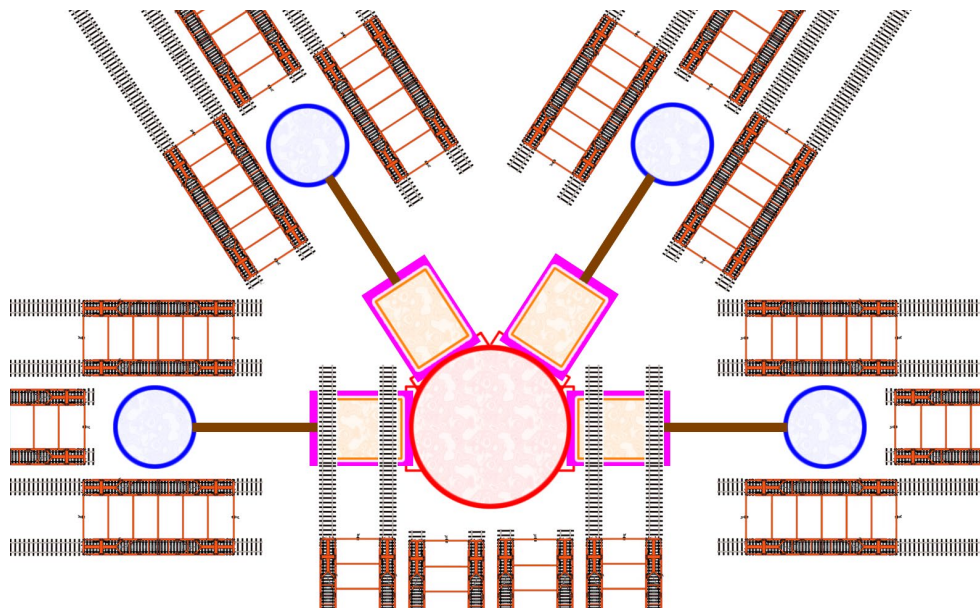


Figure 4. HTR-PM-track example layout with four reactor vessels supported by one equipment excavation.
Source: Climate Moonshot Business Plan; concept by Glenn Weinreb.

2. Excavation, earthworks, and precision rock-cutting machines - \$95 million

Full-scale or near-full-scale prototypes for HTR-PM deep excavation and PWR bulk excavation/foundation preparation, using common controls and interchangeable tools where practical.

Subphase	Principal activity and deliverable	Cost
2A	Geology, tool, and excavation-method competition for both site architectures	\$10M
2B	HTR-PM shaft/deep-excavation machine preliminary design	\$20M
2C	PWR bulk excavation, basemat preparation, and precision rock-finishing machine design	\$20M
2D	Common machine prototype fabrication and subsystem qualification	\$20M
2E	Dual-track non-nuclear excavation and foundation-preparation demonstrations	\$15M
2F	Reliability growth and replicable manufacturing package	\$10M

Decision gate

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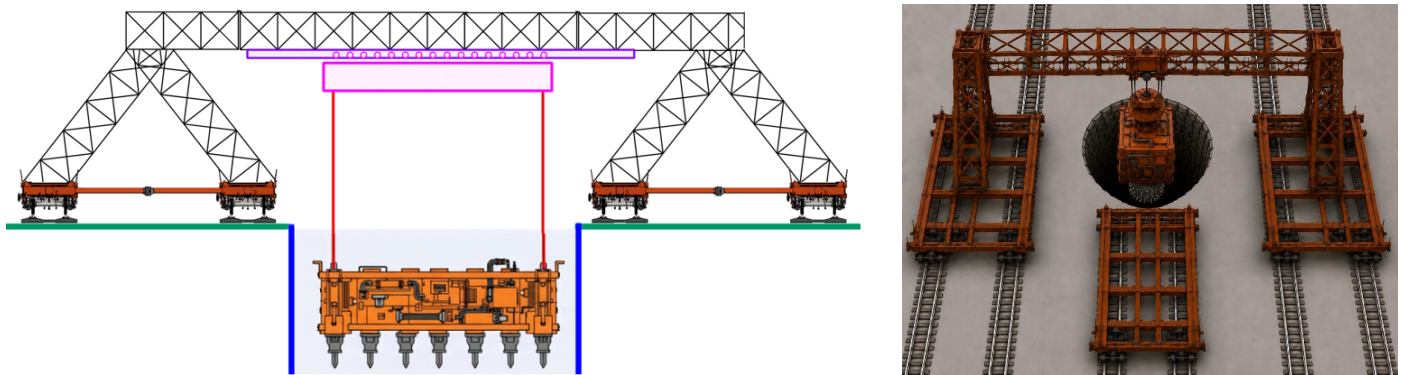


Figure 5. Gantry-like crane concept supporting excavation; adaptable tooling is a common-platform objective.
Source: Climate Moonshot Business Plan; concept by Glenn Weinreb.

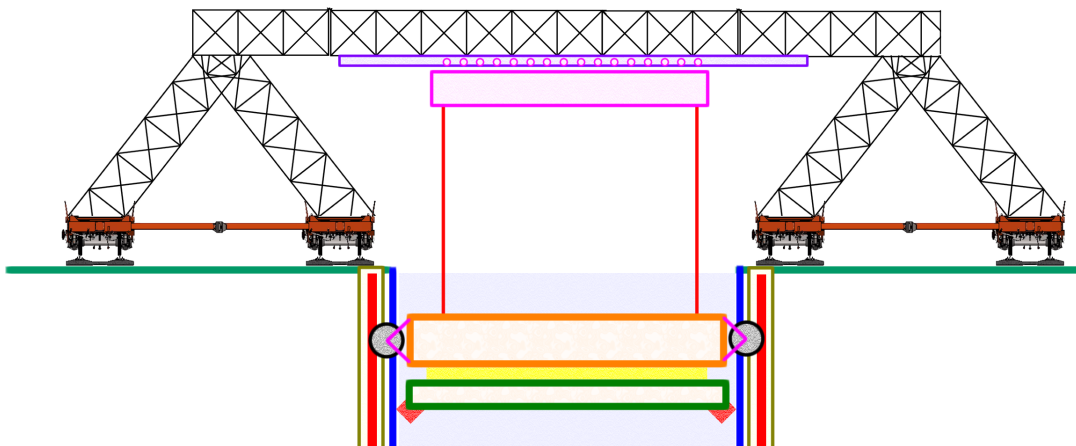


Figure 6. Conceptual precision rock-finishing machine for the HTR-PM track; PWR tooling would address basemat and nuclear-island geometry.

Source: Climate Moonshot Business Plan; concept by Glenn Weinreb.

3. Material handling, spoil removal, and machine exchange - \$55 million

Integrated material-flow and machine-exchange systems that keep both HTR-PM and PWR construction fronts supplied without waiting on haulage, staging, or maintenance.

Subphase	Principal activity and deliverable	Cost
3A	Material-flow requirements and concepts for both reference plants	\$5M
3B	HTR-PM vertical spoil, hoist, and shaft-logistics design	\$10M
3C	PWR horizontal excavation, laydown, and high-volume material-logistics design	\$10M
3D	Common conveyors, crushers, hoists, docking, utilities, and controls	\$15M
3E	Dual-track throughput, jam, maintenance, and recovery demonstration	\$10M
3F	Final scale-up design and operating package	\$5M

Decision gate

The largest fabrication or pilot commitment remains conditional until requirements, interfaces, safety, quality, cost, schedule, and independent preliminary-design review are complete.

4. Heavy lift, gantry, crane, rail, and positioning systems - \$95 million

Prototype heavy-handling systems with standardized lifting interfaces and reactor-specific fixtures for repeated HTR-PM cells and large PWR nuclear-island components/modules.

Subphase	Principal activity and deliverable	Cost
4A	Loads, geometry, rail, crane, and nuclear-lifting requirements for both reference plants	\$10M
4B	HTR-PM rail-mounted gantry, trolley, and repeated-cell handling design	\$15M
4C	PWR heavy-lift, temporary gantry, crane, and large-module installation design	\$15M
4D	Common lifting tools, controls, prototype fabrication, and factory proof testing	\$30M
4E	Dual-track pilot installation, proof-load testing, and repeated precision moves	\$18M
4F	Reliability growth and Chinese code-compliance package	\$7M

Decision gate

The largest fabrication or pilot commitment remains conditional until requirements, interfaces, safety, quality, cost, schedule, and independent preliminary-design review are complete.

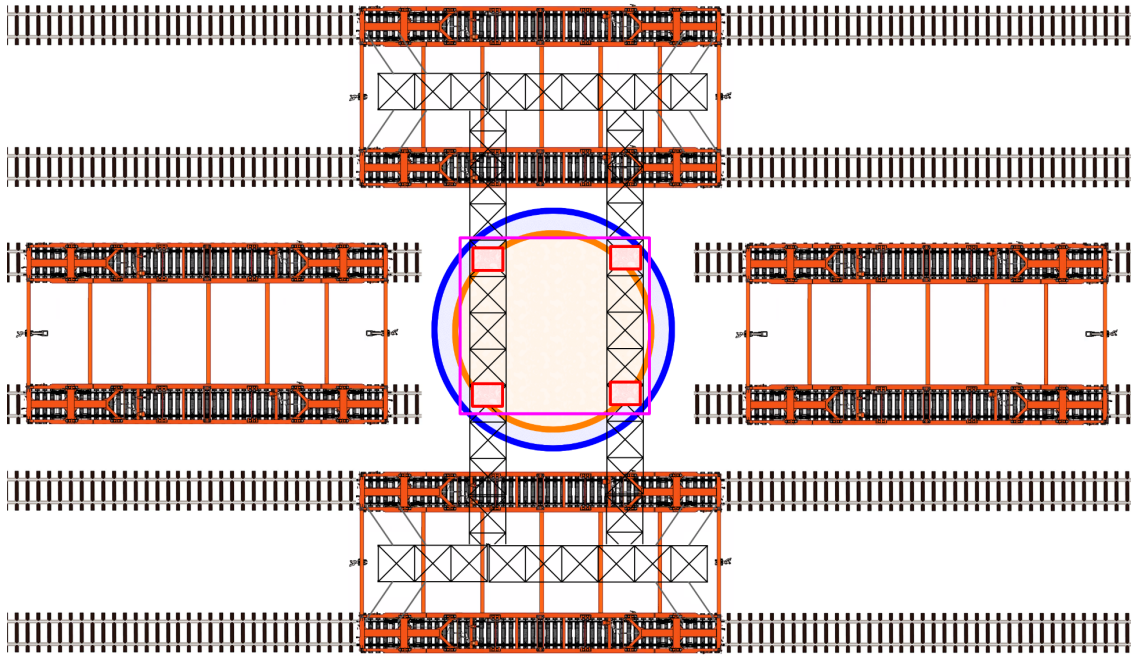


Figure 7. Conceptual rail-mounted gantry with a three-axis trolley; one candidate common heavy-handling platform. Source: Climate Moonshot Business Plan; concept by Glenn Weinreb.

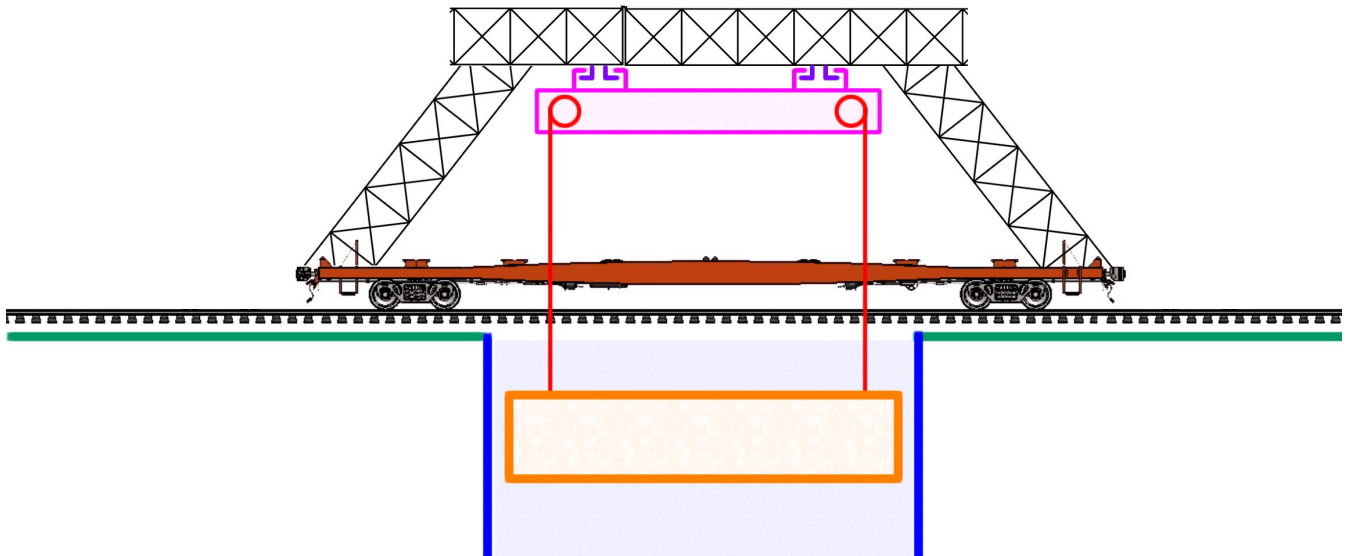


Figure 8. Gantry crane, side view.
Source: Climate Moonshot Business Plan; concept by Glenn Weinreb.

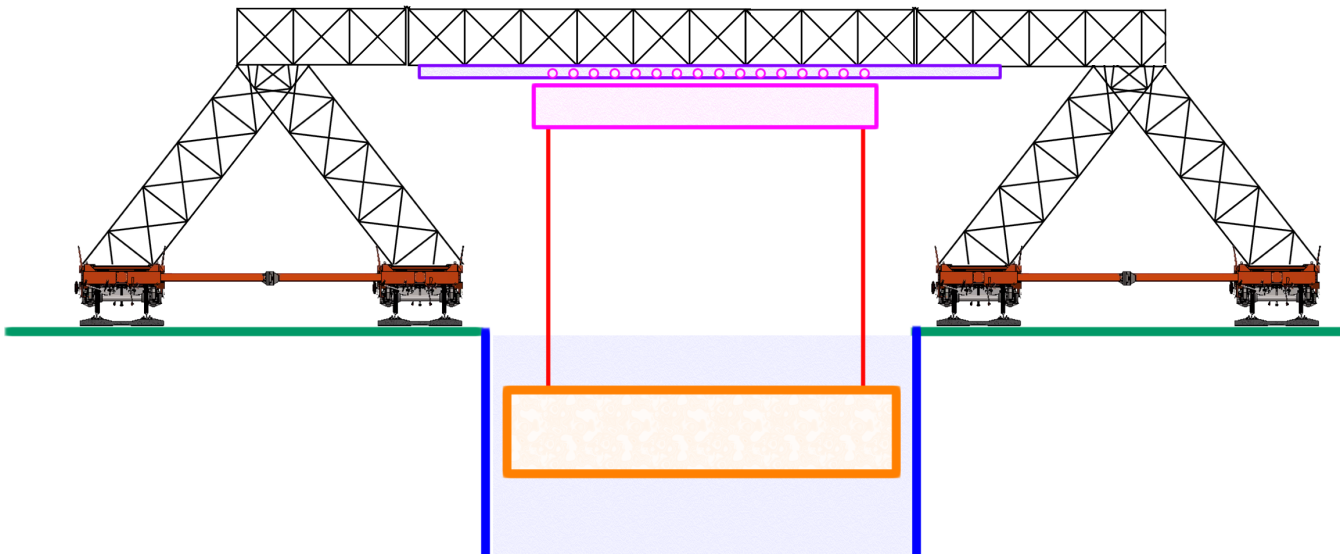


Figure 9. Gantry crane, front view.

Source: Climate Moonshot Business Plan; concept by Glenn Weinreb.

5. Concrete, rebar, formwork, steel-liner, and structural automation - \$150 million

Automated structural construction for HTR-PM lined excavations and PWR basemat/containment work, including rebar, embedments, concrete, steel liners, inspection, and digital records.

Subphase	Principal activity and deliverable	Cost
5A	Structural-system comparison, materials, and qualification plan	\$15M
5B	Automated rebar, embedments, anchors, and as-built verification	\$30M
5C	Modular formwork, batching, placement, curing, sensing, and concrete inspection	\$25M
5D	PWR steel-liner and structural-module fabrication/installation automation	\$25M
5E	Full-scale HTR-PM lining and PWR basemat/containment representative demonstrations	\$40M
5F	Reliability, code support, and final construction package	\$15M

Decision gate

The largest fabrication or pilot commitment remains conditional until requirements, interfaces, safety, quality, cost, schedule, and independent preliminary-design review are complete.

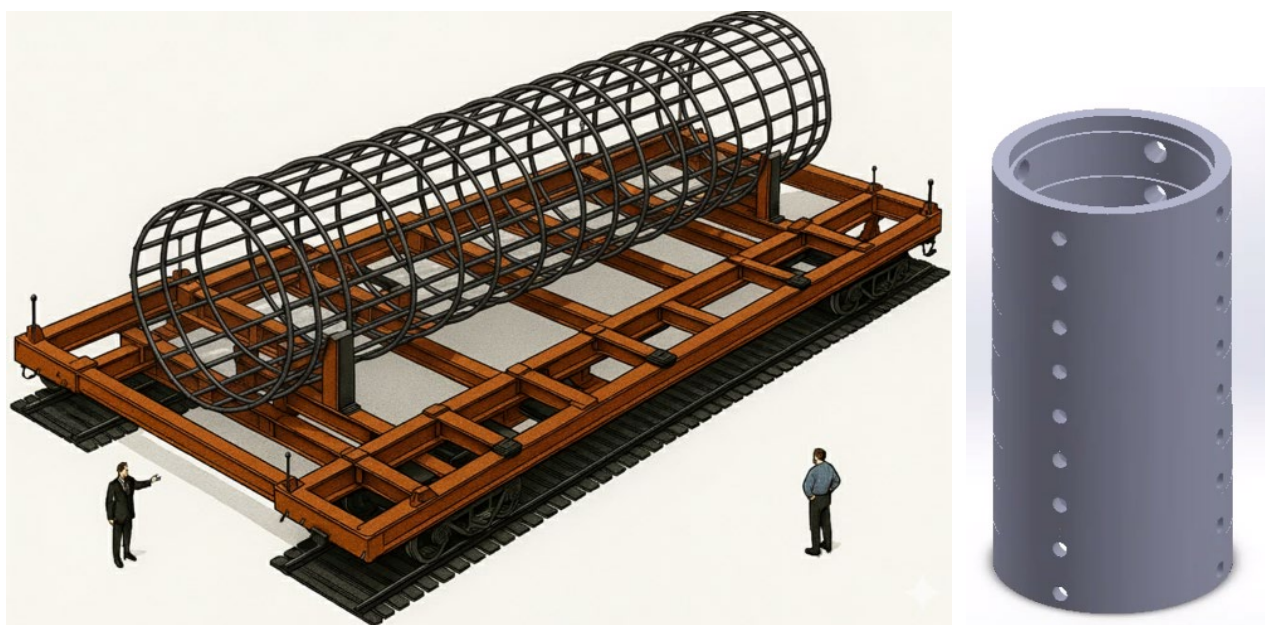


Figure 10. Conceptual rebar cage transported on a large rail platform; similar off-site fabrication principles can be tested for PWR reinforcement assemblies.

Source: Climate Moonshot Business Plan; concept by Glenn Weinreb.

6. Heavy-module transport and site-logistics system - \$80 million

Reusable transport and staging systems for factory-to-site movement of HTR-PM modules and PWR structural/mechanical modules, with standardized site handoff interfaces.

Subphase	Principal activity and deliverable	Cost
6A	Cargo, route, bridge, port, factory, and site-interface requirements	\$8M
6B	Standardized rail/SPMT/heavy-transport platform design competition	\$14M
6C	Loading, transfer, temporary track/road, staging, and route equipment	\$10M
6D	Prototype transport-platform and transfer-equipment fabrication	\$22M
6E	Loaded route, curve, grade, transfer, and crane/gantry-handoff demonstrations	\$18M
6F	Open interface standard and deployment package	\$8M

Decision gate

The largest fabrication or pilot commitment remains conditional until requirements, interfaces, safety, quality, cost, schedule, and independent preliminary-design review are complete.

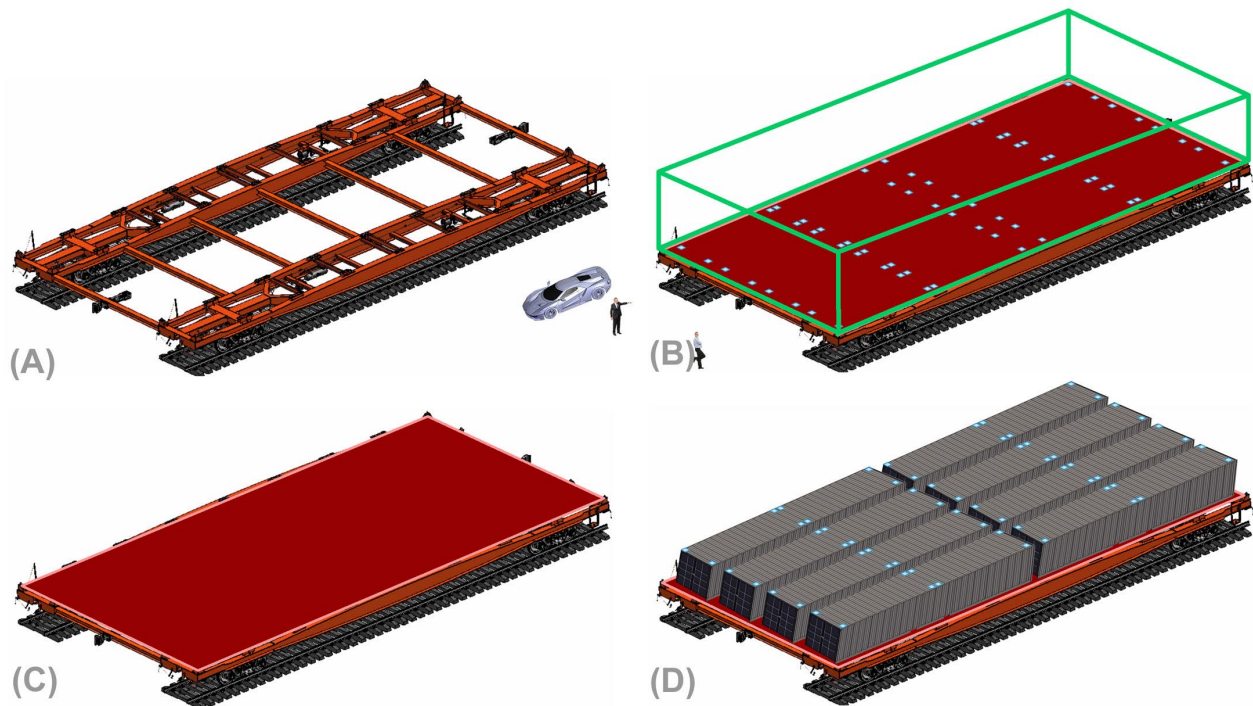


Figure 11. Double-width railcars or multi-rail platforms support large and heavy loads; the program would compare rail, SPMT, and site-specific alternatives.

Source: Climate Moonshot Business Plan; concept by Glenn Weinreb.

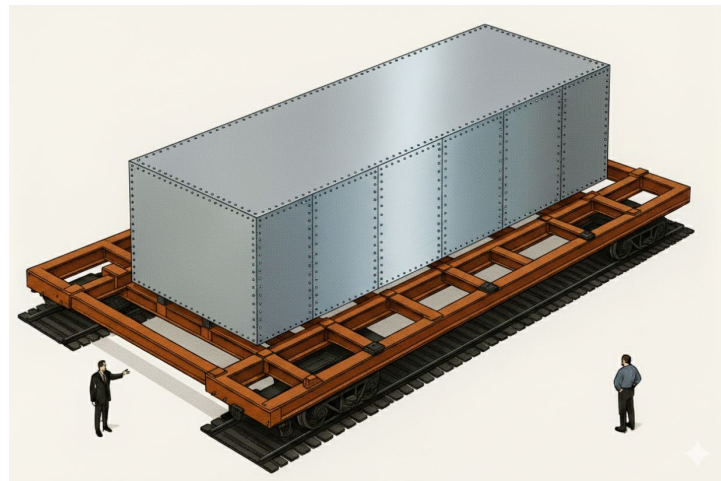


Figure 12. Equipment bins or modules are transported from factory or shipyard to the nuclear site; module envelopes differ between HTR-PM and PWR tracks.

Source: Climate Moonshot Business Plan; concept by Glenn Weinreb.

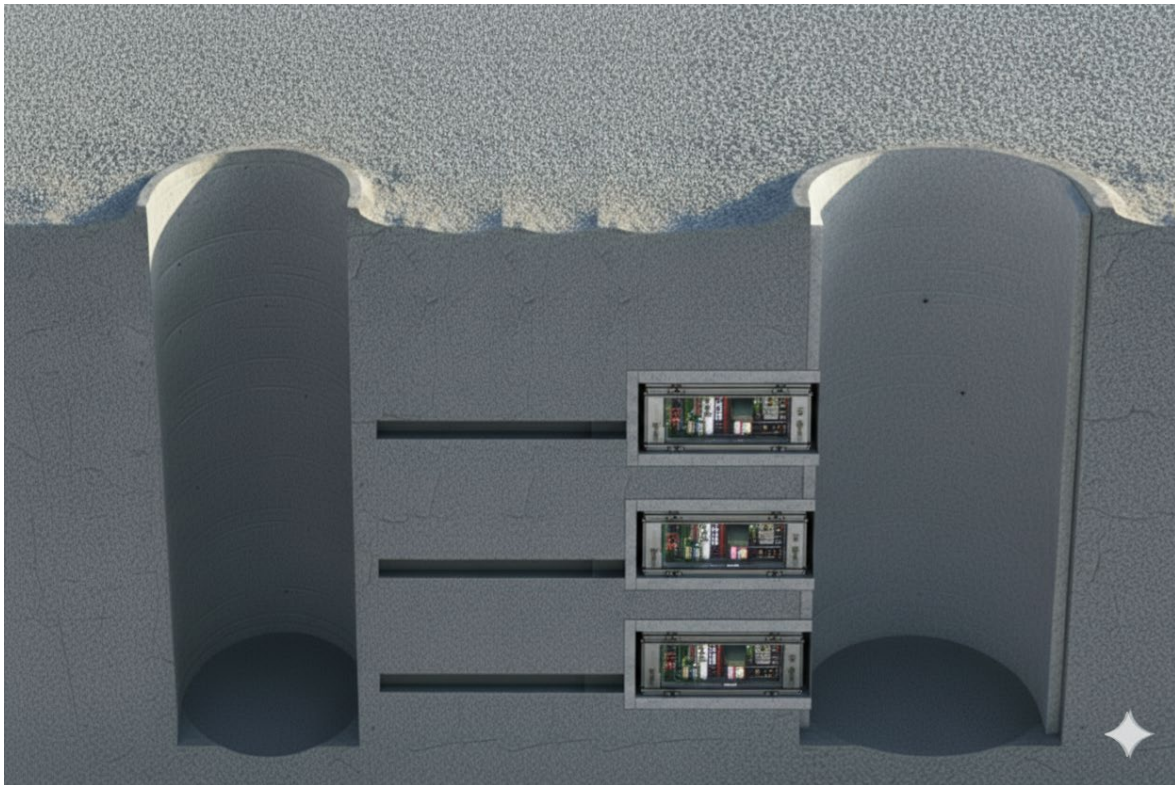


Figure 13. HTR-PM-track equipment modules mounted in concrete-lined cavities.

Source: Climate Moonshot Business Plan; concept by Glenn Weinreb.

7. Reactor-island and support-module installation automation - \$85 million

Mockups and tools to transport, position, align, connect, inspect, and repeatedly install major HTR-PM and PWR components without nuclear material.

Subphase	Principal activity and deliverable	Cost
7A	Module, datum, connection, tolerance, and inspection architecture	\$8M
7B	HTR-PM reactor-vessel, steam-generator, and support-module simulators	\$12M
7C	PWR reactor-vessel, steam-generator, pressurizer, pump, and structural-module simulators	\$15M
7D	Placement, alignment, bolting, fit-up, welding-assist, NDE, and connection tools	\$20M
7E	Dual-track end-to-end installation and repeatability demonstrations	\$22M
7F	Final interface standard and nuclear-qualification gap plan	\$8M

Decision gate

The largest fabrication or pilot commitment remains conditional until requirements, interfaces, safety, quality, cost, schedule, and independent preliminary-design review are complete.

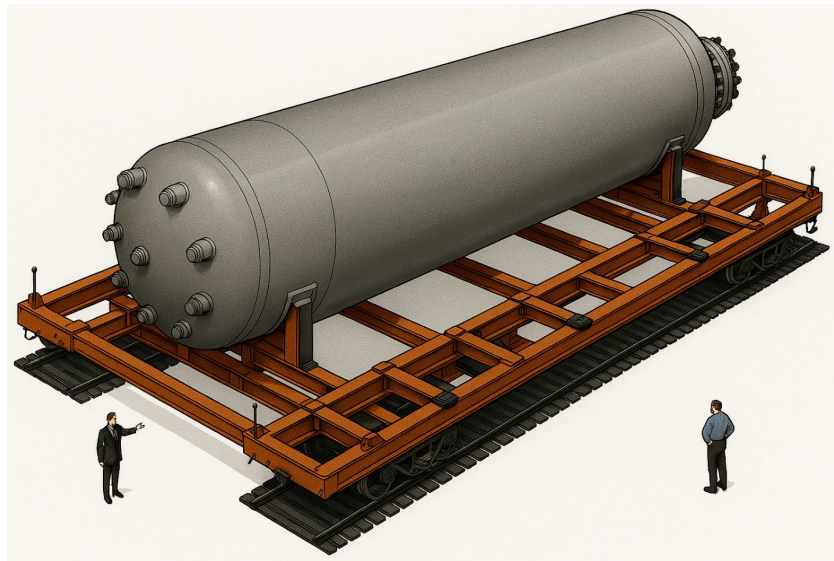


Figure 14. Reactor vessel transported from factory to site; the PWR track requires separate transport and lifting fixtures for much larger primary-system components.
Source: Climate Moonshot Business Plan; concept by Glenn Weinreb.

8. Digital twin, autonomy, metrology, and nuclear QA data thread - \$65 million

One integrated planning, control, metrology, configuration, quality, and auditable as-built data thread supporting both reactor construction tracks.

Subphase	Principal activity and deliverable	Cost
8A	China data architecture, identifiers, records, access, and cybersecurity	\$8M
8B	HTR-PM and PWR plant/site/machine/logistics 4-D digital twins	\$12M
8C	Supervisory autonomy, geofencing, safe stop, intervention, and fault recovery	\$15M
8D	Metrology, material traceability, inspection, NDE, and nonconformance integration	\$12M
8E	Pilot operating center and cyber/safety exercises	\$10M
8F	Open software/data release and regulated handoff package	\$8M

Decision gate

The largest fabrication or pilot commitment remains conditional until requirements, interfaces, safety, quality, cost, schedule, and independent preliminary-design review are complete.

9. Integrated dual-track pilot site and end-to-end demonstration - \$55 million

Shared non-nuclear pilot with distinct HTR-PM and PWR test zones where the common machine fleet and reactor-specific tooling operate end to end and produce independent evidence.

Subphase	Principal activity and deliverable	Cost
9A	China pilot-site selection, environmental review, and dual-track design	\$7M
9B	Civil works, test zones, tracks/roads, utilities, workshops, control room, and safety systems	\$13M
9C	Subsystem installation and integration	\$10M
9D	Progressive commissioning and test-readiness review	\$8M
9E	Repeated HTR-PM and PWR construction campaigns and independent audit	\$12M
9F	Phase II readiness review and first-site handoff	\$5M

Decision gate

The largest fabrication or pilot commitment remains conditional until requirements, interfaces, safety, quality, cost, schedule, and independent preliminary-design review are complete.

10. Program management, nuclear QA, China licensing support, and independent review - \$30 million

Owner-side program office controlling the common platform, two reference designs, contracts, interfaces, cost, schedule, safety, quality, data rights, independent review, and transition.

Subphase	Principal activity and deliverable	Cost
10A	Program formation, governance, China implementation plan, and financial controls	\$5M
10B	Requirements, procurement, baseline, and dual-reference interface control	\$5M
10C	Design, supplier, manufacturing, and nuclear QA oversight	\$6M
10D	Pilot safety, testing, environmental, security, and regulator engagement	\$7M
10E	Final audit, lifecycle economics, comparative technology assessment, and Phase II decision package	\$7M

Decision gate

The largest fabrication or pilot commitment remains conditional until requirements, interfaces, safety, quality, cost, schedule, and independent preliminary-design review are complete.

11. Central contingency and risk reserve - \$200 million

Reserve is held by the funding source and released only after a written problem statement, alternatives analysis, independent review, updated cost/schedule estimate, and conflict check.

Reserve stage	Max.	Examples
Requirements and reference design	\$25M	Unexpected limits on HTR-PM or PWR design data; China licensing/code studies; alternative site or structural concepts; added baseline measurements.
Prototype design	\$35M	Second-source concepts, failed tool tests, structural redesign, controls or functional-safety changes, HTR-PM/PWR interface divergence.
Fabrication and pilot site	\$55M	Supplier failure, long-lead material, rework, pilot-site changes, inflation, extraordinary heavy logistics, replacement mockups.
Integration and test	\$65M	Damaged prototypes, failed dual-track tests, additional pilot cycles, hardware/software/interface redesign, failure investigation.
Final readiness	\$20M	Additional reliability runs, final deficiencies, China licensing/QA documents, cost-model verification, schedule recovery.

Program-level gates

Gate	Date	Decision
Mission and requirements review	Month 9	Are both China reference plants, site envelopes, common-machine targets, design rights, licensing assumptions, and economic metrics defined?
Concept down-selection	Month 18	Which tasks should use common machines, HTR-PM-specific tooling, PWR-specific tooling, or conventional construction?
Preliminary design review	Month 24	Are designs, mockups, pilot site, interfaces, safety, cost, and schedule credible enough to build?
Pilot construction authorization	Month 32	Should full-scale HTR-PM and PWR test articles and prototype installation proceed?
Integrated test readiness	Month 42	Are both test zones safe, configured, independently reviewed, and ready for repeated machine campaigns?
Phase II readiness review	Month 60	Is there enough safety, quality, performance, cost, schedule, and licensing evidence to justify first licensed HTR-PM and/or PWR deployments?

Automated Construction Costs

Prompt to AI: Enclosed is a \$1B proposal to automate the construction of a nuclear power plant ("nuclear_power_automate_construction_fund, v1e.docx"). This standardizes on HTR-PM. In theory, one could instead automate the construction of a PWR that is similar to that which has been built in China over the last 5 years. Please compare: (a) Automated China HTR-PM, (b) Automated China PWR, (c) convention China PWR construction. In your comparison, include: (a) advantages/disadvantages, (b) build time, (b) LCOE cost per MWh of electricity, (b) LCOE cost per MWh of heat, (c) CAPEX cost per Watt (site construction cost). Assume we are in China (ignore USA/European costs).

Response From AI:

Yes. A PWR could use essentially the same **construction-automation philosophy** as the HTR-PM proposal: standardized plant geometry, factory-built modules, automated excavation/concrete/rebar, robotic welding and inspection, automated heavy lifting, digital twins, and an auditable QA data thread. Your proposal is explicitly aimed at those site-construction activities rather than redesigning reactor physics, and it correctly says that the \$1 billion R&D effort itself does **not** guarantee a particular plant CAPEX or electricity price.

My conclusion is that **if the objective is lowest-cost electricity, I would probably standardize the automation program on a Chinese Hualong-One-class PWR rather than HTR-PM. If industrial heat at 500°C+ is a major objective, HTR-PM becomes much more attractive.**

Estimated China comparison

These are **mature, nth-of-a-kind planning estimates**, not costs demonstrated today for an automated reactor. I am assuming Chinese labor/supply-chain costs, standardized repeated construction, roughly 90% capacity factor, 60-year life, about 7% real cost of capital, and no long-distance transmission.

	Automated China HTR-PM	Automated China PWR	Conventional China PWR
Reference plant	HTR-PM600-type, multiple reactor modules	Hualong One/HPR1000-class	Hualong One/HPR1000-class
Approx. electrical plant size	~600–1,200 MWe multi-module	~1,100 MWe/unit	~1,100 MWe/unit
Construction time	3–4 yr	3.5–4.5 yr	5–7 yr, ~6 yr typical
Total overnight plant CAPEX	\$1.7–2.1/W _e	\$1.45–1.75/W _e	\$2.0–2.5/W _e
Site-executed construction portion of CAPEX	\$0.30–0.45/W _e	\$0.35–0.50/W _e	\$0.75–1.00/W _e
Electricity LCOE	\$32–41/MWh _e	\$27–34/MWh _e	\$34–45/MWh _e

Central electricity estimate	~\$36/MWh	~\$30/MWh	~\$39/MWh
Levelized reactor heat cost	~\$13–17/MWh _{th}	~\$9–11/MWh _{th}	~\$11–14/MWh _{th}
Heat quality	Excellent: ~520–567°C steam	Much lower: <300°C steam	Much lower: <300°C steam
Main advantage	High-temperature heat + inherently safe modular architecture	Lowest likely electricity cost	Lowest technology/development risk
Main disadvantage	More reactors/steam generators/fuel systems per GW; less mature fleet	PWR construction remains geometrically complex	More site labor, longer schedule and financing period

Important: the \$/MWh-heat figures measure thermal energy quantity, not thermodynamic quality. One MWh of PWR heat below ~300°C is not economically equivalent to one MWh of HTR-PM steam at ~520–567°C. The latter can directly serve many petrochemical and other high-temperature industrial processes. HTR-PM's original designers report 250 MW_{th} per module and 567°C steam in the design configuration; more recent operating work describes ~520°C steam and specifically contrasts it with HPR1000 steam below 300°C ([reference](#)).

1. Automated Chinese PWR: probably the electricity winner

I think this is the strongest alternative to the HTR-PM program.

The biggest advantage is that **China has already done much of the difficult standardization work**. CNNC says Hualong One now has 41 units approved, under construction or operating, supported by nearly 6,000 enterprises and thousands of established standards and procedures. The first Hualong One took 68.7 months, or about 5.7 years, to construct ([reference](#)). Recent Chinese projects are already introducing digital construction, modularization, automated welding, integrated heavy lifts and even construction robots, so this would be an aggressive extension of something China is already doing rather than starting from scratch.

Economically, that matters enormously. Published work has used roughly **\$2,500/kW_e** as an overnight construction cost for a Hualong One built in China ([reference](#)). If the automation system cuts the site-executed portion roughly in half while leaving reactor vessels, steam generators, turbines, pumps, I&C and other factory equipment largely unchanged, I get a mature plant around **\$1.45–1.75/W**, versus roughly \$2–2.5/W for today's Chinese PWR construction.

That leads to my roughly **\$27–34/MWh** automated-PWR estimate.

The main problem is that a PWR is harder to turn into an assembly line at the site. It has a large containment, enormous quantities of safety-grade concrete and rebar, large interconnected water systems, dense piping/cabling and a relatively large number of site-installed safety-class systems. The automation can substantially improve construction, but it cannot simply delete those systems.

2. Automated HTR-PM: better architecture for automation and far better for process heat

HTR-PM has a very different attraction.

The reactor is deliberately divided into small, repetitive modules. Your proposed system takes this considerably further by putting repeated reactor/heat-exchanger assemblies into standardized excavations and using the same gantry, railcars, excavation machinery, rebar/concrete machinery and module-placement equipment over and over. That is unusually well suited to a construction factory operating in the field.

There is also a genuine safety/design simplification. HTR-PM achieves decay-heat removal through its low power density and modular core rather than depending on the same type of emergency cooling architecture as a conventional LWR. The Chinese developers describe this as the "divide 1 into N" safety approach.

But there is an economic penalty: you need **many more nuclear components per GW**. Multiple reactor vessels, graphite cores, steam generators, helium blowers, fuel-handling systems and associated components substitute for one very large PWR nuclear steam supply system.

This is not just theoretical. The original HTR-PM economic work estimated that a mature multi-module HTR-PM plant would cost about **110–120% as much as an equivalent Chinese PWR**. Even more significantly, a 2025 paper from the HTR-PM team says the plant's current power-generation cost is approximately **20% above that of standard commercial PWRs**, although the authors expect cogeneration and batch production to narrow the difference.

That is why I put automated HTR-PM electricity at roughly **\$32–41/MWh**, versus **\$27–34/MWh for the automated PWR**.

But this comparison changes dramatically when you value heat. HTR-PM was explicitly designed for cogeneration and high-temperature process heat. Its design produces 567°C steam, and its developers have identified industrial heat and hydrogen production as major applications.

3. Conventional Chinese PWR: already surprisingly difficult to beat

This is an important point for the \$1 billion program.

China is **not starting with Western nuclear construction economics**. Its conventional PWR construction industry is already highly standardized, has enormous manufacturing scale and is increasingly using modular construction and digital tools.

INL's work on nuclear construction finds that construction rather than nuclear physics is a dominant cost driver, and shows why reducing installation labor and construction time can have large effects. It also cautions that costs are distributed across civil structures, equipment installation, engineering and construction management rather than residing solely in concrete and rebar.

So, an automated Chinese PWR might reduce a \$2.2/W plant to perhaps \$1.6/W. It probably **will not** reduce a \$2.2/W Chinese reactor to \$0.7/W simply by automating the construction site, because much of the remaining cost is factory-manufactured nuclear equipment, turbines, electrical systems, engineering, QA, commissioning, owner costs and other items that the construction machinery does not eliminate.

That distinction is why I recommend tracking both **total plant CAPEX** and **site-executed construction CAPEX**. The latter is what your \$1 billion program most directly attacks.

Advantages and disadvantages

Automated HTR-PM. Its strongest advantages are passive/inherent safety characteristics, very high-temperature steam, small repetitive reactor modules, strong compatibility with factory manufacture, repetitive excavations and machine operations, and potentially much simpler industrial cogeneration. Its disadvantages are the large number of reactor modules per GW, multiple pressure vessels and steam generators, helium machinery, TRISO fuel requirements, relatively low power density, and a much smaller operating/construction experience base. The HTR-PM entered commercial operation only in December 2023, whereas China now has a large Hualong One industrial ecosystem.

Automated PWR. Its biggest advantages are the mature Chinese design and supply chain, roughly 1.1 GW from one reactor, huge economies of scale in reactor equipment, existing regulatory familiarity, proven fuel cycle, thousands of suppliers, and dozens of units providing learning opportunities. The disadvantages are the large containment and civil structures, complex high-pressure water systems, dense piping/cabling and safety systems, and the fact that a large PWR is somewhat less naturally divisible into identical construction cells.

Conventional Chinese PWR. Its enormous advantage is certainty: China knows how to build it today, and the first Hualong One achieved a 68.7-month schedule. There is no need to spend five years first developing a radically new construction system. Its disadvantages are a longer construction critical path, more field labor, more opportunities for rework and a larger interest-during-construction burden.

What I would do with the \$1 billion program

I would **not yet lock the \$1 billion program exclusively to HTR-PM**.

I would make the first approximately **\$50–100 million an 18–24 month head-to-head design study** in which the exact same automation philosophy is applied to:

1. a standardized **HTR-PM600**, and
2. a standardized **Hualong One/HPR1000**.

Then calculate bottom-up, machine by machine and construction step by construction step:

\$/W site construction → total \$/W plant → months to fuel load → \$/MWh electricity → \$/MWh useful process heat.

There is a very plausible result in which **PWR wins electricity by perhaps \$5–8/MWh while HTR-PM wins decisively when the customer needs 500°C-class heat.**

And there is an especially interesting third possibility: **use both**. China itself is now pursuing exactly that logic at Xuwei, where Phase I combines Hualong One PWRs with a high-temperature gas-cooled reactor and is intended primarily to supply large quantities of industrial steam while also generating electricity.

For a climate strategy that includes electricity **and** ammonia/hydrogen/industrial heat, that mixed architecture may ultimately be more important than deciding that one reactor technology must do everything.

Cost Comparison: Electricity Generation Only

Prompt to AI: In China, what are costs for: (a) new coal fired power plant, (b) marginal cost for existing coal fired power plant, (c) solar farm, and (d) wind farm. In summary table, include: (a) electricity LCOE (\$/MWh electricity), (b) heat LCOE (\$/MWh heat), (c) construction capex (\$/watt). Also, in summarize table, include: (a) new Automated China HTR-PM, (b) new Automated China PWR, and (c) new conventional China PWR. In summary table, show values as a range (e.g. \$24 to 32/MWh). After you produce that table, produce another table that is similar yet do not show the range and instead show average value within range rounded off to nearest dollar.

Response From AI:

Links to References
<https://chatgpt.com/share/6a778d0b-5ee8-83ea-8792-db8fa4903a37>

For a China-only comparison, I would use the following as reasonable planning numbers. These are plant-gate costs in roughly 2025–2026 USD, with no 1,000-km transmission, battery storage, renewable firming, CCS, or explicit incremental carbon charge. For CAPEX, I am using total installed/overnight construction CAPEX per watt of electric nameplate capacity, because that is the most comparable measure across technologies.

For renewables, IRENA's newest data put China's 2025 average LCOE at \$36/MWh for solar PV and \$27/MWh for onshore wind. Recent Chinese government project data show substantial project-to-project CAPEX variation for both solar and wind.

Table 1 — Recommended ranges

China generation technology	Electricity LCOE / marginal cost (\$/MWh _e)	Heat LCOE (\$/MWh _{th})	Construction CAPEX (\$/W _e)
New coal plant — ultra-supercritical	\$43 to \$58	\$18 to \$24	\$0.50 to \$0.70
Existing coal plant — marginal cost	\$35 to \$45	\$16 to \$20	N/A — already sunk
New solar farm	\$25 to \$45	\$26 to \$47*	\$0.40 to \$0.60
New onshore wind farm	\$22 to \$32	\$23 to \$34*	\$0.65 to \$1.00
New Automated China HTR-PM	\$32 to \$41	\$13 to \$17	\$1.70 to \$2.10
New Automated China PWR	\$27 to \$34	\$9 to \$11	\$1.45 to \$1.75
New conventional China PWR	\$34 to \$45	\$11 to \$14	\$2.00 to \$2.50

The coal figures deserve a little explanation. A recent Chinese study estimated 2025 coal-fired LCOE in Gansu at about **\$43/MWh**. Meanwhile, China's National Energy Administration reported March 2026 Qinhuangdao 5,500-kcal coal at RMB 682/tonne under long-term contracts and RMB 753/tonne spot.

Modern new Chinese coal units are targeted below 270 grams of standard coal/kWh, while the fleet average target was below 300 g/kWh. Recent 2-GW ultra-supercritical projects also show extremely low Chinese construction costs—for example, a government project list gives RMB 8 billion for a 2,000-MW project, roughly RMB 4,000/kW. Taken together, those support roughly **\$43–58/MWh for a new plant** and **\$35–45/MWh for the marginal operating cost of an existing plant**, with mine-mouth plants toward the low end and coastal coal purchasers toward the high end ([reference](#)).

For the three nuclear cases, I retained the assumptions from our previous comparison. They should be treated differently from the coal/wind/solar figures: **the two automated reactor designs do not exist yet at those costs**, so these are engineering target/scenario estimates. Your \$1 billion proposal itself explicitly says that the program develops and demonstrates construction automation and does not guarantee a specific overnight capital cost or electricity price. As a reality check, published analysis has used about **\$2,500/kW for a Chinese Hualong One**, while CNNC reports that the first Hualong One took 68.7 months to construct and that China now has a very large standardized supply chain behind it.

Table 2 — Midpoint of each range

This is simply the **arithmetic midpoint** of Table 1, not a claim that the midpoint is the actual national average. I rounded energy costs to the nearest \$1/MWh and CAPEX to the nearest \$0.01/W.

China generation technology	Electricity LCOE / marginal cost (\$/MWh _e)	Heat LCOE (\$/MWh _{th})	Construction CAPEX (\$/W _e)
New coal plant — ultra-supercritical	\$51	\$21	\$0.60
Existing coal plant — marginal cost	\$40	\$18	N/A — sunk
New solar farm	\$35	\$37*	\$0.50
New onshore wind farm	\$27	\$29*	\$0.83
New Automated China HTR-PM	\$37	\$15	\$1.90
New Automated China PWR	\$31	\$10	\$1.60
New conventional China PWR	\$40	\$13	\$2.25

* **Solar/wind heat requires an important qualification.** I assumed the electricity is converted to heat with approximately 98% efficient electric resistance heating, with a small allowance for heater equipment. It does **not** include thermal storage, batteries, backup generation, or the cost imposed by intermittent operation. Thus \$29/MWh of wind-derived heat is not equivalent operationally to \$15/MWh of continuously available HTR-PM steam.

There is also a major **heat-quality difference** hidden in the table. HTR-PM currently produces steam at approximately **520°C**, whereas Hualong-One-class PWR steam is below **300°C**. The HTR-PM researchers specifically identify industrial process heat as one of the architecture's advantages; they also report that today's demonstration HTR-PM electricity costs about 20% more than standard commercial PWR power.

So, for the particular climate/industrial strategy we have been examining, **Table 2 highlights the central tradeoff very clearly:**

- Cheapest intermittent electricity: **onshore wind $\approx$ \$27/MWh**
- Cheapest hypothesized firm 24/7 electricity: **automated PWR $\approx$ \$31/MWh**
- Solar: **$\approx$ \$35/MWh**
- Automated HTR-PM: **$\approx$ \$37/MWh**, but with valuable $\sim 520^{\circ}\text{C}$ heat
- Existing coal marginal generation: **$\approx$ \$40/MWh**
- Conventional new Chinese PWR: **$\approx$ \$40/MWh**
- New coal: **$\approx$ \$51/MWh**

That last comparison is potentially quite important for your proposal: **if the automated-PWR assumptions can actually be achieved, building a new automated PWR would cost less per MWh than merely burning coal in many existing Chinese coal plants.** That is a much stronger economic claim than simply saying nuclear competes with *new* coal, although it is also the claim that most needs to be demonstrated experimentally.

Cost Comparison: Electricity Generation + Transmission

Prompt to AI: HTR-PM is safer than PWR and therefore can be placed closer to a metropolitan area, with less transmission line cost. Please redo the previous table and only show 3 columns: (a) LCOE electricity cost at gate of power plant, (b) LCOE cost for transmission lines, and (c) total LCOE (i.e. sum of column 'a' and 'b'). All numbers shown would be \$/MWh for electricity.

Response From AI:

Yes. If we explicitly give HTR-PM a **siting advantage** because its passive/inherent safety allows it to be located substantially closer to the metropolitan load, the comparison changes.

I would use the following representative siting assumptions: **HTR-PM 50 km; PWR 300 km; new coal 300 km; remote wind/solar 1,000 km**. These are scenario assumptions, not Chinese regulatory minimum distances. Your HTR-PM proposal specifically selects the technology partly because loss of active cooling does not lead to fuel melting.

Revised Table 2 — Electricity delivered to metropolitan area

China generation technology	LCOE at power-plant gate (\$/MWh)	Transmission (\$/MWh)	Total delivered LCOE (\$/MWh)
New coal — ultra-supercritical	\$51	\$3	\$54
Existing coal — marginal cost	\$40	\$1*	\$41
New solar farm — 1,000 km away	\$35	\$9	\$44
New onshore wind — 1,000 km away	\$27	\$9	\$36
New Automated China HTR-PM — ~50 km away	\$37	\$1	\$38
New Automated China PWR — ~300 km away	\$31	\$3	\$34
New conventional China PWR — ~300 km away	\$40	\$3	\$43

* For existing coal, I am treating the transmission infrastructure as largely sunk and assigning about \$1/MWh for incremental transmission O&M/loss effects rather than constructing a new dedicated transmission system.

The **\$9/MWh assumption for ~1,000 km transmission** is reasonable for China. As a useful real-world benchmark, the Gansu–Shandong ±800-kV UHVDC line spans about **915 km**, cost about **RMB 20.2 billion**, and transmitted 28.8 TWh in its first year of operation. China's newer Gansu–Zhejiang line is 2,370 km, costs about RMB 35.3 billion and is designed to transmit more than 36 TWh/year. I therefore use roughly \$9/MWh as an all-in planning estimate for a heavily utilized 1,000-km UHV transmission system, including an allowance for losses.

The important result

Once transmission is included, the ranking becomes:

Automated PWR:	\$34/MWh
Wind at 1,000 km:	\$36/MWh
Automated HTR-PM near city:	\$38/MWh
Existing coal marginal:	\$41/MWh
Conventional PWR:	\$43/MWh
Solar at 1,000 km:	\$44/MWh
New coal:	\$54/MWh

There is an important implication for the HTR-PM strategy: its electricity-generation disadvantage versus an automated PWR shrinks from about **\$6/MWh at the plant gate (\$37 vs. \$31)** to about **\$4/MWh delivered (\$38 vs. \$34)** under these siting assumptions.

And HTR-PM still has something the PWR does not: **high-temperature process heat**. So, for a metropolitan/industrial complex that needs both electricity and steam, the HTR-PM could potentially become the lower-total-system-cost option even though its electricity-only LCOE remains modestly higher.

One caution: **300 km is not a physical or regulatory requirement for a Chinese PWR**. Some Chinese PWRs can and do sit much closer to population centers. So the transmission advantage should be modeled as an *HTR-PM siting hypothesis to test*, rather than assuming every PWR necessarily needs hundreds of kilometers of transmission.

Purchase Orders

Prompt to AI: For each phase of each dual-reference budget item, list illustrative purchase orders, amounts, recipients, and acceptance logic. Treat “purchase order” as a procurement package that may be a contract, grant, cooperative agreement, reimbursable agreement, or task order. Assume the primary implementation and pilot work occurs in China.

Response From AI:

Every procurement should define a controlled deliverable, acceptance test, schedule, data rights, payment milestones, Chinese code/quality requirements, and stop/advance conditions. Early awards should deliberately compare common-platform and reactor-specific approaches. Novel prototypes may use milestone-based or cost-reimbursement contracts; well-defined studies, fabrication, standard equipment, and independent reviews can increasingly use fixed price.

1. Dual-reference plant, site, and construction-system design - \$90 million

PO	Illustrative procurement	Amount	Recipient type
1A-1	China reference requirements, design-data access, and licensing strategy: lead engineering, controlled design, requirements, and technical package	\$6M	Lead China execution team / design authority
1A-2	China reference requirements, design-data access, and licensing strategy: prototype, test article, software/data system, fabrication, or field implementation	\$5M	Specialty supplier / fabricator / university / research team
1A-3	China reference requirements, design-data access, and licensing strategy: independent verification of performance, cost, safety, quality, records, and acceptance	\$4M	Owner-direct independent reviewer / test organization
1B-1	Site envelopes, civil quantities, geotechnical assumptions, and temporary works for both reference plants: lead engineering, controlled design, requirements, and technical package	\$6M	Lead China execution team / design authority
1B-2	Site envelopes, civil quantities, geotechnical assumptions, and temporary works for both reference plants: prototype, test article, software/data system, fabrication, or field implementation	\$5M	Specialty supplier / fabricator / university / research team
1B-3	Site envelopes, civil quantities, geotechnical assumptions, and temporary works for both reference plants: independent verification of performance, cost, safety, quality, records, and acceptance	\$4M	Owner-direct independent reviewer / test organization
1C-1	Design-for-automation, modularization, common interfaces, and construction sequence: lead engineering, controlled design, requirements, and technical package	\$8M	Lead China execution team / design authority
1C-2	Design-for-automation, modularization, common interfaces, and construction sequence: prototype, test	\$7M	Specialty supplier / fabricator / university / research team

PO	Illustrative procurement	Amount	Recipient type
	article, software/data system, fabrication, or field implementation		
1C-3	Design-for-automation, modularization, common interfaces, and construction sequence: independent verification of performance, cost, safety, quality, records, and acceptance	\$5M	Owner-direct independent reviewer / test organization
1D-1	HTR-PM-specific underground construction cell and machine-interface design: lead engineering, controlled design, requirements, and technical package	\$6M	Lead China execution team / design authority
1D-2	HTR-PM-specific underground construction cell and machine-interface design: prototype, test article, software/data system, fabrication, or field implementation	\$5M	Specialty supplier / fabricator / university / research team
1D-3	HTR-PM-specific underground construction cell and machine-interface design: independent verification of performance, cost, safety, quality, records, and acceptance	\$4M	Owner-direct independent reviewer / test organization
1E-1	PWR-specific basemat, containment, steel-liner, embedment, and nuclear-island construction design: lead engineering, controlled design, requirements, and technical package	\$6M	Lead China execution team / design authority
1E-2	PWR-specific basemat, containment, steel-liner, embedment, and nuclear-island construction design: prototype, test article, software/data system, fabrication, or field implementation	\$5M	Specialty supplier / fabricator / university / research team
1E-3	PWR-specific basemat, containment, steel-liner, embedment, and nuclear-island construction design: independent verification of performance, cost, safety, quality, records, and acceptance	\$4M	Owner-direct independent reviewer / test organization
1F-1	Comparative cost/schedule/siting model and final machine procurement package: lead engineering, controlled design, requirements, and technical package	\$4M	Lead China execution team / design authority
1F-2	Comparative cost/schedule/siting model and final machine procurement package: prototype, test article, software/data system, fabrication, or field implementation	\$4M	Specialty supplier / fabricator / university / research team
1F-3	Comparative cost/schedule/siting model and final machine procurement package: independent verification of performance, cost, safety, quality, records, and acceptance	\$2M	Owner-direct independent reviewer / test organization

Work-package total: \$90 million. Detailed task orders may be combined or split, but the procurement ledger must reconcile to this total and identify HTR-PM-only, PWR-only, and common-platform spending.

2. Excavation, earthworks, and precision rock-cutting machines - \$95 million

PO	Illustrative procurement	Amount	Recipient type
2A-1	Geology, tool, and excavation-method competition for both site architectures: lead engineering, controlled design,	\$4M	Lead China execution team / design authority

PO	Illustrative procurement	Amount	Recipient type
	requirements, and technical package		
2A-2	Geology, tool, and excavation-method competition for both site architectures: prototype, test article, software/data system, fabrication, or field implementation	\$4M	Specialty supplier / fabricator / university / research team
2A-3	Geology, tool, and excavation-method competition for both site architectures: independent verification of performance, cost, safety, quality, records, and acceptance	\$2M	Owner-direct independent reviewer / test organization
2B-1	HTR-PM shaft/deep-excavation machine preliminary design: lead engineering, controlled design, requirements, and technical package	\$8M	Lead China execution team / design authority
2B-2	HTR-PM shaft/deep-excavation machine preliminary design: prototype, test article, software/data system, fabrication, or field implementation	\$7M	Specialty supplier / fabricator / university / research team
2B-3	HTR-PM shaft/deep-excavation machine preliminary design: independent verification of performance, cost, safety, quality, records, and acceptance	\$5M	Owner-direct independent reviewer / test organization
2C-1	PWR bulk excavation, basemat preparation, and precision rock-finishing machine design: lead engineering, controlled design, requirements, and technical package	\$8M	Lead China execution team / design authority
2C-2	PWR bulk excavation, basemat preparation, and precision rock-finishing machine design: prototype, test article, software/data system, fabrication, or field implementation	\$7M	Specialty supplier / fabricator / university / research team
2C-3	PWR bulk excavation, basemat preparation, and precision rock-finishing machine design: independent verification of performance, cost, safety, quality, records, and acceptance	\$5M	Owner-direct independent reviewer / test organization
2D-1	Common machine prototype fabrication and subsystem qualification: lead engineering, controlled design, requirements, and technical package	\$8M	Lead China execution team / design authority
2D-2	Common machine prototype fabrication and subsystem qualification: prototype, test article, software/data system, fabrication, or field implementation	\$7M	Specialty supplier / fabricator / university / research team
2D-3	Common machine prototype fabrication and subsystem qualification: independent verification of performance, cost, safety, quality, records, and acceptance	\$5M	Owner-direct independent reviewer / test organization
2E-1	Dual-track non-nuclear excavation and foundation-preparation demonstrations: lead engineering, controlled design, requirements, and technical package	\$6M	Lead China execution team / design authority
2E-2	Dual-track non-nuclear excavation and foundation-preparation demonstrations: prototype, test article, software/data system, fabrication, or field implementation	\$5M	Specialty supplier / fabricator / university / research team
2E-3	Dual-track non-nuclear excavation and foundation-preparation demonstrations: independent verification of performance, cost, safety, quality, records, and acceptance	\$4M	Owner-direct independent reviewer / test organization
2F-1	Reliability growth and replicable manufacturing package: lead engineering, controlled design, requirements, and technical package	\$4M	Lead China execution team / design authority
2F-2	Reliability growth and replicable manufacturing package: prototype, test article, software/data system, fabrication,	\$4M	Specialty supplier / fabricator / university / research team

PO	Illustrative procurement	Amount	Recipient type
	or field implementation		
2F-3	Reliability growth and replicable manufacturing package: independent verification of performance, cost, safety, quality, records, and acceptance	\$2M	Owner-direct independent reviewer / test organization

Work-package total: \$95 million. Detailed task orders may be combined or split, but the procurement ledger must reconcile to this total and identify HTR-PM-only, PWR-only, and common-platform spending.

3. Material handling, spoil removal, and machine exchange - \$55 million

PO	Illustrative procurement	Amount	Recipient type
3A-1	Material-flow requirements and concepts for both reference plants: lead engineering, controlled design, requirements, and technical package	\$2M	Lead China execution team / design authority
3A-2	Material-flow requirements and concepts for both reference plants: prototype, test article, software/data system, fabrication, or field implementation	\$2M	Specialty supplier / fabricator / university / research team
3A-3	Material-flow requirements and concepts for both reference plants: independent verification of performance, cost, safety, quality, records, and acceptance	\$1M	Owner-direct independent reviewer / test organization
3B-1	HTR-PM vertical spoil, hoist, and shaft-logistics design: lead engineering, controlled design, requirements, and technical package	\$4M	Lead China execution team / design authority
3B-2	HTR-PM vertical spoil, hoist, and shaft-logistics design: prototype, test article, software/data system, fabrication, or field implementation	\$4M	Specialty supplier / fabricator / university / research team
3B-3	HTR-PM vertical spoil, hoist, and shaft-logistics design: independent verification of performance, cost, safety, quality, records, and acceptance	\$2M	Owner-direct independent reviewer / test organization
3C-1	PWR horizontal excavation, laydown, and high-volume material-logistics design: lead engineering, controlled design, requirements, and technical package	\$4M	Lead China execution team / design authority
3C-2	PWR horizontal excavation, laydown, and high-volume material-logistics design: prototype, test article, software/data system, fabrication, or field implementation	\$4M	Specialty supplier / fabricator / university / research team
3C-3	PWR horizontal excavation, laydown, and high-volume material-logistics design: independent verification of performance, cost, safety, quality, records, and acceptance	\$2M	Owner-direct independent reviewer / test organization
3D-1	Common conveyors, crushers, hoists, docking, utilities, and controls: lead engineering, controlled design, requirements, and technical package	\$6M	Lead China execution team / design authority
3D-2	Common conveyors, crushers, hoists, docking, utilities, and controls: prototype, test article, software/data system, fabrication, or field implementation	\$5M	Specialty supplier / fabricator / university / research team
3D-3	Common conveyors, crushers, hoists, docking, utilities, and	\$4M	Owner-direct independent

PO	Illustrative procurement	Amount	Recipient type
	controls: independent verification of performance, cost, safety, quality, records, and acceptance		reviewer / test organization
3E-1	Dual-track throughput, jam, maintenance, and recovery demonstration: lead engineering, controlled design, requirements, and technical package	\$4M	Lead China execution team / design authority
3E-2	Dual-track throughput, jam, maintenance, and recovery demonstration: prototype, test article, software/data system, fabrication, or field implementation	\$4M	Specialty supplier / fabricator / university / research team
3E-3	Dual-track throughput, jam, maintenance, and recovery demonstration: independent verification of performance, cost, safety, quality, records, and acceptance	\$2M	Owner-direct independent reviewer / test organization
3F-1	Final scale-up design and operating package: lead engineering, controlled design, requirements, and technical package	\$2M	Lead China execution team / design authority
3F-2	Final scale-up design and operating package: prototype, test article, software/data system, fabrication, or field implementation	\$2M	Specialty supplier / fabricator / university / research team
3F-3	Final scale-up design and operating package: independent verification of performance, cost, safety, quality, records, and acceptance	\$1M	Owner-direct independent reviewer / test organization

Work-package total: \$55 million. Detailed task orders may be combined or split, but the procurement ledger must reconcile to this total and identify HTR-PM-only, PWR-only, and common-platform spending.

4. Heavy lift, gantry, crane, rail, and positioning systems - \$95 million

PO	Illustrative procurement	Amount	Recipient type
4A-1	Loads, geometry, rail, crane, and nuclear-lifting requirements for both reference plants: lead engineering, controlled design, requirements, and technical package	\$4M	Lead China execution team / design authority
4A-2	Loads, geometry, rail, crane, and nuclear-lifting requirements for both reference plants: prototype, test article, software/data system, fabrication, or field implementation	\$4M	Specialty supplier / fabricator / university / research team
4A-3	Loads, geometry, rail, crane, and nuclear-lifting requirements for both reference plants: independent verification of performance, cost, safety, quality, records, and acceptance	\$2M	Owner-direct independent reviewer / test organization
4B-1	HTR-PM rail-mounted gantry, trolley, and repeated-cell handling design: lead engineering, controlled design, requirements, and technical package	\$6M	Lead China execution team / design authority
4B-2	HTR-PM rail-mounted gantry, trolley, and repeated-cell handling design: prototype, test article, software/data system, fabrication, or field implementation	\$5M	Specialty supplier / fabricator / university / research team
4B-3	HTR-PM rail-mounted gantry, trolley, and repeated-cell	\$4M	Owner-direct independent

PO	Illustrative procurement	Amount	Recipient type
	handling design: independent verification of performance, cost, safety, quality, records, and acceptance		reviewer / test organization
4C-1	PWR heavy-lift, temporary gantry, crane, and large-module installation design: lead engineering, controlled design, requirements, and technical package	\$6M	Lead China execution team / design authority
4C-2	PWR heavy-lift, temporary gantry, crane, and large-module installation design: prototype, test article, software/data system, fabrication, or field implementation	\$5M	Specialty supplier / fabricator / university / research team
4C-3	PWR heavy-lift, temporary gantry, crane, and large-module installation design: independent verification of performance, cost, safety, quality, records, and acceptance	\$4M	Owner-direct independent reviewer / test organization
4D-1	Common lifting tools, controls, prototype fabrication, and factory proof testing: lead engineering, controlled design, requirements, and technical package	\$12M	Lead China execution team / design authority
4D-2	Common lifting tools, controls, prototype fabrication, and factory proof testing: prototype, test article, software/data system, fabrication, or field implementation	\$10M	Specialty supplier / fabricator / university / research team
4D-3	Common lifting tools, controls, prototype fabrication, and factory proof testing: independent verification of performance, cost, safety, quality, records, and acceptance	\$8M	Owner-direct independent reviewer / test organization
4E-1	Dual-track pilot installation, proof-load testing, and repeated precision moves: lead engineering, controlled design, requirements, and technical package	\$7M	Lead China execution team / design authority
4E-2	Dual-track pilot installation, proof-load testing, and repeated precision moves: prototype, test article, software/data system, fabrication, or field implementation	\$6M	Specialty supplier / fabricator / university / research team
4E-3	Dual-track pilot installation, proof-load testing, and repeated precision moves: independent verification of performance, cost, safety, quality, records, and acceptance	\$5M	Owner-direct independent reviewer / test organization
4F-1	Reliability growth and Chinese code-compliance package: lead engineering, controlled design, requirements, and technical package	\$3M	Lead China execution team / design authority
4F-2	Reliability growth and Chinese code-compliance package: prototype, test article, software/data system, fabrication, or field implementation	\$2M	Specialty supplier / fabricator / university / research team
4F-3	Reliability growth and Chinese code-compliance package: independent verification of performance, cost, safety, quality, records, and acceptance	\$2M	Owner-direct independent reviewer / test organization

Work-package total: \$95 million. Detailed task orders may be combined or split, but the procurement ledger must reconcile to this total and identify HTR-PM-only, PWR-only, and common-platform spending.

5. Concrete, rebar, formwork, steel-liner, and structural automation - \$150 million

PO	Illustrative procurement	Amount	Recipient type
5A-1	Structural-system comparison, materials, and qualification plan: lead engineering, controlled design, requirements, and technical package	\$6M	Lead China execution team / design authority
5A-2	Structural-system comparison, materials, and qualification plan: prototype, test article, software/data system, fabrication, or field implementation	\$5M	Specialty supplier / fabricator / university / research team
5A-3	Structural-system comparison, materials, and qualification plan: independent verification of performance, cost, safety, quality, records, and acceptance	\$4M	Owner-direct independent reviewer / test organization
5B-1	Automated rebar, embedments, anchors, and as-built verification: lead engineering, controlled design, requirements, and technical package	\$12M	Lead China execution team / design authority
5B-2	Automated rebar, embedments, anchors, and as-built verification: prototype, test article, software/data system, fabrication, or field implementation	\$10M	Specialty supplier / fabricator / university / research team
5B-3	Automated rebar, embedments, anchors, and as-built verification: independent verification of performance, cost, safety, quality, records, and acceptance	\$8M	Owner-direct independent reviewer / test organization
5C-1	Modular formwork, batching, placement, curing, sensing, and concrete inspection: lead engineering, controlled design, requirements, and technical package	\$10M	Lead China execution team / design authority
5C-2	Modular formwork, batching, placement, curing, sensing, and concrete inspection: prototype, test article, software/data system, fabrication, or field implementation	\$9M	Specialty supplier / fabricator / university / research team
5C-3	Modular formwork, batching, placement, curing, sensing, and concrete inspection: independent verification of performance, cost, safety, quality, records, and acceptance	\$6M	Owner-direct independent reviewer / test organization
5D-1	PWR steel-liner and structural-module fabrication/installation automation: lead engineering, controlled design, requirements, and technical package	\$10M	Lead China execution team / design authority
5D-2	PWR steel-liner and structural-module fabrication/installation automation: prototype, test article, software/data system, fabrication, or field implementation	\$9M	Specialty supplier / fabricator / university / research team
5D-3	PWR steel-liner and structural-module fabrication/installation automation: independent verification of performance, cost, safety, quality, records, and acceptance	\$6M	Owner-direct independent reviewer / test organization
5E-1	Full-scale HTR-PM lining and PWR basemat/containment representative demonstrations: lead engineering, controlled design, requirements, and technical package	\$16M	Lead China execution team / design authority
5E-2	Full-scale HTR-PM lining and PWR basemat/containment representative demonstrations: prototype, test article, software/data system, fabrication, or field implementation	\$14M	Specialty supplier / fabricator / university / research team
5E-3	Full-scale HTR-PM lining and PWR basemat/containment	\$10M	Owner-direct independent

PO	Illustrative procurement	Amount	Recipient type
	representative demonstrations: independent verification of performance, cost, safety, quality, records, and acceptance		reviewer / test organization
5F-1	Reliability, code support, and final construction package: lead engineering, controlled design, requirements, and technical package	\$6M	Lead China execution team / design authority
5F-2	Reliability, code support, and final construction package: prototype, test article, software/data system, fabrication, or field implementation	\$5M	Specialty supplier / fabricator / university / research team
5F-3	Reliability, code support, and final construction package: independent verification of performance, cost, safety, quality, records, and acceptance	\$4M	Owner-direct independent reviewer / test organization

Work-package total: \$150 million. Detailed task orders may be combined or split, but the procurement ledger must reconcile to this total and identify HTR-PM-only, PWR-only, and common-platform spending.

6. Heavy-module transport and site-logistics system - \$80 million

PO	Illustrative procurement	Amount	Recipient type
6A-1	Cargo, route, bridge, port, factory, and site-interface requirements: lead engineering, controlled design, requirements, and technical package	\$3M	Lead China execution team / design authority
6A-2	Cargo, route, bridge, port, factory, and site-interface requirements: prototype, test article, software/data system, fabrication, or field implementation	\$3M	Specialty supplier / fabricator / university / research team
6A-3	Cargo, route, bridge, port, factory, and site-interface requirements: independent verification of performance, cost, safety, quality, records, and acceptance	\$2M	Owner-direct independent reviewer / test organization
6B-1	Standardized rail/SPMT/heavy-transport platform design competition: lead engineering, controlled design, requirements, and technical package	\$6M	Lead China execution team / design authority
6B-2	Standardized rail/SPMT/heavy-transport platform design competition: prototype, test article, software/data system, fabrication, or field implementation	\$5M	Specialty supplier / fabricator / university / research team
6B-3	Standardized rail/SPMT/heavy-transport platform design competition: independent verification of performance, cost, safety, quality, records, and acceptance	\$3M	Owner-direct independent reviewer / test organization
6C-1	Loading, transfer, temporary track/road, staging, and route equipment: lead engineering, controlled design, requirements, and technical package	\$4M	Lead China execution team / design authority
6C-2	Loading, transfer, temporary track/road, staging, and route equipment: prototype, test article, software/data system, fabrication, or field implementation	\$4M	Specialty supplier / fabricator / university / research team
6C-3	Loading, transfer, temporary track/road, staging, and route equipment: independent verification of performance, cost, safety, quality, records, and acceptance	\$2M	Owner-direct independent reviewer / test organization

PO	Illustrative procurement	Amount	Recipient type
6D-1	Prototype transport-platform and transfer-equipment fabrication: lead engineering, controlled design, requirements, and technical package	\$9M	Lead China execution team / design authority
6D-2	Prototype transport-platform and transfer-equipment fabrication: prototype, test article, software/data system, fabrication, or field implementation	\$8M	Specialty supplier / fabricator / university / research team
6D-3	Prototype transport-platform and transfer-equipment fabrication: independent verification of performance, cost, safety, quality, records, and acceptance	\$5M	Owner-direct independent reviewer / test organization
6E-1	Loaded route, curve, grade, transfer, and crane/gantry-handoff demonstrations: lead engineering, controlled design, requirements, and technical package	\$7M	Lead China execution team / design authority
6E-2	Loaded route, curve, grade, transfer, and crane/gantry-handoff demonstrations: prototype, test article, software/data system, fabrication, or field implementation	\$6M	Specialty supplier / fabricator / university / research team
6E-3	Loaded route, curve, grade, transfer, and crane/gantry-handoff demonstrations: independent verification of performance, cost, safety, quality, records, and acceptance	\$5M	Owner-direct independent reviewer / test organization
6F-1	Open interface standard and deployment package: lead engineering, controlled design, requirements, and technical package	\$3M	Lead China execution team / design authority
6F-2	Open interface standard and deployment package: prototype, test article, software/data system, fabrication, or field implementation	\$3M	Specialty supplier / fabricator / university / research team
6F-3	Open interface standard and deployment package: independent verification of performance, cost, safety, quality, records, and acceptance	\$2M	Owner-direct independent reviewer / test organization

Work-package total: \$80 million. Detailed task orders may be combined or split, but the procurement ledger must reconcile to this total and identify HTR-PM-only, PWR-only, and common-platform spending.

7. Reactor-island and support-module installation automation - \$85 million

PO	Illustrative procurement	Amount	Recipient type
7A-1	Module, datum, connection, tolerance, and inspection architecture: lead engineering, controlled design, requirements, and technical package	\$3M	Lead China execution team / design authority
7A-2	Module, datum, connection, tolerance, and inspection architecture: prototype, test article, software/data system, fabrication, or field implementation	\$3M	Specialty supplier / fabricator / university / research team
7A-3	Module, datum, connection, tolerance, and inspection architecture: independent verification of performance, cost, safety, quality, records, and acceptance	\$2M	Owner-direct independent reviewer / test organization
7B-1	HTR-PM reactor-vessel, steam-generator, and support-module simulators: lead engineering, controlled design,	\$5M	Lead China execution team / design authority

PO	Illustrative procurement	Amount	Recipient type
	requirements, and technical package		
7B-2	HTR-PM reactor-vessel, steam-generator, and support-module simulators: prototype, test article, software/data system, fabrication, or field implementation	\$4M	Specialty supplier / fabricator / university / research team
7B-3	HTR-PM reactor-vessel, steam-generator, and support-module simulators: independent verification of performance, cost, safety, quality, records, and acceptance	\$3M	Owner-direct independent reviewer / test organization
7C-1	PWR reactor-vessel, steam-generator, pressurizer, pump, and structural-module simulators: lead engineering, controlled design, requirements, and technical package	\$6M	Lead China execution team / design authority
7C-2	PWR reactor-vessel, steam-generator, pressurizer, pump, and structural-module simulators: prototype, test article, software/data system, fabrication, or field implementation	\$5M	Specialty supplier / fabricator / university / research team
7C-3	PWR reactor-vessel, steam-generator, pressurizer, pump, and structural-module simulators: independent verification of performance, cost, safety, quality, records, and acceptance	\$4M	Owner-direct independent reviewer / test organization
7D-1	Placement, alignment, bolting, fit-up, welding-assist, NDE, and connection tools: lead engineering, controlled design, requirements, and technical package	\$8M	Lead China execution team / design authority
7D-2	Placement, alignment, bolting, fit-up, welding-assist, NDE, and connection tools: prototype, test article, software/data system, fabrication, or field implementation	\$7M	Specialty supplier / fabricator / university / research team
7D-3	Placement, alignment, bolting, fit-up, welding-assist, NDE, and connection tools: independent verification of performance, cost, safety, quality, records, and acceptance	\$5M	Owner-direct independent reviewer / test organization
7E-1	Dual-track end-to-end installation and repeatability demonstrations: lead engineering, controlled design, requirements, and technical package	\$9M	Lead China execution team / design authority
7E-2	Dual-track end-to-end installation and repeatability demonstrations: prototype, test article, software/data system, fabrication, or field implementation	\$8M	Specialty supplier / fabricator / university / research team
7E-3	Dual-track end-to-end installation and repeatability demonstrations: independent verification of performance, cost, safety, quality, records, and acceptance	\$5M	Owner-direct independent reviewer / test organization
7F-1	Final interface standard and nuclear-qualification gap plan: lead engineering, controlled design, requirements, and technical package	\$3M	Lead China execution team / design authority
7F-2	Final interface standard and nuclear-qualification gap plan: prototype, test article, software/data system, fabrication, or field implementation	\$3M	Specialty supplier / fabricator / university / research team
7F-3	Final interface standard and nuclear-qualification gap plan: independent verification of performance, cost, safety, quality, records, and acceptance	\$2M	Owner-direct independent reviewer / test organization

Work-package total: \$85 million. Detailed task orders may be combined or split, but the procurement ledger must reconcile to this total and identify HTR-PM-only, PWR-only, and common-platform spending.

8. Digital twin, autonomy, metrology, and nuclear QA data thread - \$65 million

PO	Illustrative procurement	Amount	Recipient type
8A-1	China data architecture, identifiers, records, access, and cybersecurity: lead engineering, controlled design, requirements, and technical package	\$3M	Lead China execution team / design authority
8A-2	China data architecture, identifiers, records, access, and cybersecurity: prototype, test article, software/data system, fabrication, or field implementation	\$3M	Specialty supplier / fabricator / university / research team
8A-3	China data architecture, identifiers, records, access, and cybersecurity: independent verification of performance, cost, safety, quality, records, and acceptance	\$2M	Owner-direct independent reviewer / test organization
8B-1	HTR-PM and PWR plant/site/machine/logistics 4-D digital twins: lead engineering, controlled design, requirements, and technical package	\$5M	Lead China execution team / design authority
8B-2	HTR-PM and PWR plant/site/machine/logistics 4-D digital twins: prototype, test article, software/data system, fabrication, or field implementation	\$4M	Specialty supplier / fabricator / university / research team
8B-3	HTR-PM and PWR plant/site/machine/logistics 4-D digital twins: independent verification of performance, cost, safety, quality, records, and acceptance	\$3M	Owner-direct independent reviewer / test organization
8C-1	Supervisory autonomy, geofencing, safe stop, intervention, and fault recovery: lead engineering, controlled design, requirements, and technical package	\$6M	Lead China execution team / design authority
8C-2	Supervisory autonomy, geofencing, safe stop, intervention, and fault recovery: prototype, test article, software/data system, fabrication, or field implementation	\$5M	Specialty supplier / fabricator / university / research team
8C-3	Supervisory autonomy, geofencing, safe stop, intervention, and fault recovery: independent verification of performance, cost, safety, quality, records, and acceptance	\$4M	Owner-direct independent reviewer / test organization
8D-1	Metrology, material traceability, inspection, NDE, and nonconformance integration: lead engineering, controlled design, requirements, and technical package	\$5M	Lead China execution team / design authority
8D-2	Metrology, material traceability, inspection, NDE, and nonconformance integration: prototype, test article, software/data system, fabrication, or field implementation	\$4M	Specialty supplier / fabricator / university / research team
8D-3	Metrology, material traceability, inspection, NDE, and nonconformance integration: independent verification of performance, cost, safety, quality, records, and acceptance	\$3M	Owner-direct independent reviewer / test organization
8E-1	Pilot operating center and cyber/safety exercises: lead engineering, controlled design, requirements, and technical package	\$4M	Lead China execution team / design authority
8E-2	Pilot operating center and cyber/safety exercises: prototype, test article, software/data system, fabrication, or field implementation	\$4M	Specialty supplier / fabricator / university / research team
8E-3	Pilot operating center and cyber/safety exercises: independent verification of performance, cost, safety,	\$2M	Owner-direct independent reviewer / test organization

PO	Illustrative procurement	Amount	Recipient type
	quality, records, and acceptance		
8F-1	Open software/data release and regulated handoff package: lead engineering, controlled design, requirements, and technical package	\$3M	Lead China execution team / design authority
8F-2	Open software/data release and regulated handoff package: prototype, test article, software/data system, fabrication, or field implementation	\$3M	Specialty supplier / fabricator / university / research team
8F-3	Open software/data release and regulated handoff package: independent verification of performance, cost, safety, quality, records, and acceptance	\$2M	Owner-direct independent reviewer / test organization

Work-package total: \$65 million. Detailed task orders may be combined or split, but the procurement ledger must reconcile to this total and identify HTR-PM-only, PWR-only, and common-platform spending.

9. Integrated dual-track pilot site and end-to-end demonstration - \$55 million

PO	Illustrative procurement	Amount	Recipient type
9A-1	China pilot-site selection, environmental review, and dual-track design: lead engineering, controlled design, requirements, and technical package	\$3M	Lead China execution team / design authority
9A-2	China pilot-site selection, environmental review, and dual-track design: prototype, test article, software/data system, fabrication, or field implementation	\$2M	Specialty supplier / fabricator / university / research team
9A-3	China pilot-site selection, environmental review, and dual-track design: independent verification of performance, cost, safety, quality, records, and acceptance	\$2M	Owner-direct independent reviewer / test organization
9B-1	Civil works, test zones, tracks/roads, utilities, workshops, control room, and safety systems: lead engineering, controlled design, requirements, and technical package	\$5M	Lead China execution team / design authority
9B-2	Civil works, test zones, tracks/roads, utilities, workshops, control room, and safety systems: prototype, test article, software/data system, fabrication, or field implementation	\$5M	Specialty supplier / fabricator / university / research team
9B-3	Civil works, test zones, tracks/roads, utilities, workshops, control room, and safety systems: independent verification of performance, cost, safety, quality, records, and acceptance	\$3M	Owner-direct independent reviewer / test organization
9C-1	Subsystem installation and integration: lead engineering, controlled design, requirements, and technical package	\$4M	Lead China execution team / design authority
9C-2	Subsystem installation and integration: prototype, test article, software/data system, fabrication, or field implementation	\$4M	Specialty supplier / fabricator / university / research team
9C-3	Subsystem installation and integration: independent verification of performance, cost, safety, quality, records,	\$2M	Owner-direct independent reviewer / test organization

PO	Illustrative procurement	Amount	Recipient type
	and acceptance		
9D-1	Progressive commissioning and test-readiness review: lead engineering, controlled design, requirements, and technical package	\$3M	Lead China execution team / design authority
9D-2	Progressive commissioning and test-readiness review: prototype, test article, software/data system, fabrication, or field implementation	\$3M	Specialty supplier / fabricator / university / research team
9D-3	Progressive commissioning and test-readiness review: independent verification of performance, cost, safety, quality, records, and acceptance	\$2M	Owner-direct independent reviewer / test organization
9E-1	Repeated HTR-PM and PWR construction campaigns and independent audit: lead engineering, controlled design, requirements, and technical package	\$5M	Lead China execution team / design authority
9E-2	Repeated HTR-PM and PWR construction campaigns and independent audit: prototype, test article, software/data system, fabrication, or field implementation	\$4M	Specialty supplier / fabricator / university / research team
9E-3	Repeated HTR-PM and PWR construction campaigns and independent audit: independent verification of performance, cost, safety, quality, records, and acceptance	\$3M	Owner-direct independent reviewer / test organization
9F-1	Phase II readiness review and first-site handoff: lead engineering, controlled design, requirements, and technical package	\$2M	Lead China execution team / design authority
9F-2	Phase II readiness review and first-site handoff: prototype, test article, software/data system, fabrication, or field implementation	\$2M	Specialty supplier / fabricator / university / research team
9F-3	Phase II readiness review and first-site handoff: independent verification of performance, cost, safety, quality, records, and acceptance	\$1M	Owner-direct independent reviewer / test organization

Work-package total: \$55 million. Detailed task orders may be combined or split, but the procurement ledger must reconcile to this total and identify HTR-PM-only, PWR-only, and common-platform spending.

10. Program management, nuclear QA, China licensing support, and independent review - \$30 million

PO	Illustrative procurement	Amount	Recipient type
10A-1	Program formation, governance, China implementation plan, and financial controls: lead engineering, controlled design, requirements, and technical package	\$2M	Lead China execution team / design authority
10A-2	Program formation, governance, China implementation plan, and financial controls: prototype, test article, software/data system, fabrication, or field implementation	\$2M	Specialty supplier / fabricator / university / research team
10A-3	Program formation, governance, China implementation plan, and financial controls: independent verification of	\$1M	Owner-direct independent reviewer / test organization

PO	Illustrative procurement	Amount	Recipient type
	performance, cost, safety, quality, records, and acceptance		
10B-1	Requirements, procurement, baseline, and dual-reference interface control: lead engineering, controlled design, requirements, and technical package	\$2M	Lead China execution team / design authority
10B-2	Requirements, procurement, baseline, and dual-reference interface control: prototype, test article, software/data system, fabrication, or field implementation	\$2M	Specialty supplier / fabricator / university / research team
10B-3	Requirements, procurement, baseline, and dual-reference interface control: independent verification of performance, cost, safety, quality, records, and acceptance	\$1M	Owner-direct independent reviewer / test organization
10C-1	Design, supplier, manufacturing, and nuclear QA oversight: lead engineering, controlled design, requirements, and technical package	\$2M	Lead China execution team / design authority
10C-2	Design, supplier, manufacturing, and nuclear QA oversight: prototype, test article, software/data system, fabrication, or field implementation	\$2M	Specialty supplier / fabricator / university / research team
10C-3	Design, supplier, manufacturing, and nuclear QA oversight: independent verification of performance, cost, safety, quality, records, and acceptance	\$2M	Owner-direct independent reviewer / test organization
10D-1	Pilot safety, testing, environmental, security, and regulator engagement: lead engineering, controlled design, requirements, and technical package	\$3M	Lead China execution team / design authority
10D-2	Pilot safety, testing, environmental, security, and regulator engagement: prototype, test article, software/data system, fabrication, or field implementation	\$2M	Specialty supplier / fabricator / university / research team
10D-3	Pilot safety, testing, environmental, security, and regulator engagement: independent verification of performance, cost, safety, quality, records, and acceptance	\$2M	Owner-direct independent reviewer / test organization
10E-1	Final audit, lifecycle economics, comparative technology assessment, and Phase II decision package: lead engineering, controlled design, requirements, and technical package	\$3M	Lead China execution team / design authority
10E-2	Final audit, lifecycle economics, comparative technology assessment, and Phase II decision package: prototype, test article, software/data system, fabrication, or field implementation	\$2M	Specialty supplier / fabricator / university / research team
10E-3	Final audit, lifecycle economics, comparative technology assessment, and Phase II decision package: independent verification of performance, cost, safety, quality, records, and acceptance	\$2M	Owner-direct independent reviewer / test organization

Work-package total: \$30 million. Detailed task orders may be combined or split, but the procurement ledger must reconcile to this total and identify HTR-PM-only, PWR-only, and common-platform spending.

11. Contingent reserve task orders - up to \$200 million

Reserve stage	Contingent task orders	Max.
Requirements/design	Additional HTR-PM/PWR design-data access, alternative reference configurations, China-code/licensing analysis, added geology, baseline cost/schedule measurement, or early recovery.	\$25M
Prototype design	Second-source concept, failed tool redesign, added structural/controls tests, common-platform split into reactor-specific variants, safety changes, red team.	\$35M
Fabrication/site	Replacement supplier, long-lead parts, manufacturing rework, pilot-site change, replacement HTR-PM/PWR mockups, extraordinary logistics.	\$55M
Integration/test	Replacement articles, extra dual-track pilot cycles, hardware/software/interface redesign, failure investigation, reliability growth.	\$65M
Final readiness	Additional reliability runs, deficiencies, licensing/QA documents, independent economics verification, schedule recovery.	\$20M

Contracting principles

- Use about ten lead contract vehicles corresponding to the baseline work packages, with competitive task orders and specialty subcontracts; score common-platform reuse explicitly.
- Separate HTR-PM and PWR design authorities from independent verification and from the owner-side machine acceptance function.
- Tie hardware payments to requirements, design review, long-lead procurement, fabrication, factory acceptance, HTR-PM/PWR pilot installation, demonstrated performance, and final data handoff.
- Retain broad foreground rights in sponsor-funded construction machines and interfaces while protecting narrowly defined pre-existing reactor-vendor and supplier background IP.
- Include termination, step-in, source-code access, technical-data handoff, spare-parts, maintenance, and second-source manufacturing rights compatible with Chinese law and security restrictions.

Purchase Order Recipients

Prompt to AI: Who might receive the purchase orders in a China-based HTR-PM + PWR construction-automation program? Identify illustrative Chinese organizations and, where useful, international specialty suppliers; explain competition and teaming; and separate performers from independent reviewers.

Response From AI:

The organizations below are illustrative candidates, not endorsements, availability commitments, or prequalified bidders. The China implementation strategy should make maximum use of the existing HTR-PM and Hualong One industrial base while competing construction machinery and digital systems on measurable performance. Reactor vendors and EPCs may supply controlled interface data and execute work, but they should not independently certify their own cost, schedule, safety, quality, or machine-performance claims.

Capability	Illustrative organizations	Potential contribution
HTR-PM/HTGR reference	Tsinghua INET; China Huaneng; Chinergy; CNNC; Shanghai Electric	HTR-PM construction reference, operating experience, component envelopes, safety boundaries, vendor interfaces, design-data access, and HTR-PM600 scale-up assumptions.
Hualong One / PWR reference	CNNC; China Nuclear Power Engineering (CNPE); China National Nuclear Power; CGN; CGN Engineering; major Chinese NSSS/equipment suppliers	Hualong One/HPR1000 reference geometry, construction sequence, modularization, component loads, QA requirements, supply-chain and serial-build experience.
Nuclear construction / civil EPC	China Nuclear Industry Huaxing Construction; other qualified CNNC construction subsidiaries; CGN Engineering; POWERCHINA Nuclear Engineering; major Chinese civil contractors	Nuclear civil work, basemat/containment, rebar/concrete, steel liners, modularization, constructability, Chinese QA, site logistics, commissioning interfaces.
Excavation and heavy equipment	China Railway Engineering Equipment Group; XCMG; SANY; LiuGong; Zoomlion; qualified tunneling/mining suppliers	Shaft/tunnel boring, bulk excavation, cutting, loading, conveyors, cranes, concrete machinery, wear tools, automation, maintenance, and scale manufacturing.
Automation and field robotics	Tsinghua; Tongji; Zhejiang University; Shanghai Jiao Tong; Harbin Institute of Technology; Chinese construction-equipment OEM automation teams	Perception, machine control, remote supervision, functional safety, path planning, force control, robotized rebar/concrete/finishing, bounded field trials.
Heavy lift, rail, SPMT, and port handling	XCMG; SANY; Zoomlion; CRRC; ZPMC; Chinese heavy-transport and port engineering firms; international specialists where justified	Heavy cranes, gantries, synchronized transport, rail vehicles, SPMTs, engineered rigging, route analysis, proof testing, precision module placement.
Concrete, rebar, liners, and structures	China Nuclear Industry Huaxing Construction; CSEEC; MCC; Tongji/Tsinghua structural teams; SANY/Zoomlion concrete	Nuclear structures, full-scale tests, rebar prefabrication/placement, formwork, concrete, PWR liners/structural modules, inspection and

Capability	Illustrative organizations	Potential contribution
	systems; qualified steel fabricators	qualification.
Digital engineering and metrology	Huawei and other qualified Chinese industrial ICT providers; SUPCON/HollySys; Hexagon/Siemens/Bentley China where permitted; Tsinghua/Tongji	BIM/4-D planning, digital twins, industrial networks, configuration, machine guidance, reality capture, metrology, product lifecycle and as-built verification.
Independent integration and review	Independent Chinese universities/labs, qualified test institutes, China Academy of Building Research capabilities, independent cost/schedule specialists, international peer reviewers where permitted	System integration audit, structural/test witnessing, cyber review, cost/schedule assessment, QA audit, acceptance verification, public-interest program review.

Assignments by work package

Work package	Illustrative execution and independent review approach
1. Dual-reference plant, site, and construction-system design	Parallel HTR-PM and Hualong One design-authority teams plus an owner systems integrator; independent constructability/economics review.
2. Excavation, earthworks, and precision rock-cutting machines	Chinese tunnel/shaft and heavy-equipment OEMs; nuclear civil contractor; geotechnical universities; independent full-scale test witnesses.
3. Material handling, spoil removal, and machine exchange	Mining/material-flow suppliers, hoist/conveyor firms, site-logistics contractors, controls integrator; independent throughput/recovery test team.
4. Heavy lift, gantry, crane, rail, and positioning systems	Chinese crane/heavy-lift/rail/SPMT OEMs and nuclear EPCs; separate structural/lifting-code reviewer and proof-load witness.
5. Concrete, rebar, formwork, steel-liner, and structural automation	Huaxing/qualified nuclear civil teams, concrete/rebar OEMs, steel-liner fabricators, structural universities; independent materials/NDE/QA laboratories.
6. Heavy-module transport and site-logistics system	Heavy-transport, CRRC/rail, SPMT, port/route/bridge engineers, factory module teams; independent transport safety and route audit.
7. Reactor-island and support-module installation automation	HTR-PM and PWR vendor/EPC installation teams, heavy fabrication, industrial robotics, welding/NDE/metrology suppliers; owner-direct installation reviewers.
8. Digital twin, autonomy, metrology, and nuclear QA data thread	Chinese industrial digital/controls providers, universities, metrology vendors and nuclear QA specialists; independent software V&V and cyber teams.
9. Integrated dual-track pilot site and end-to-end demonstration	Neutral China-based system integrator with separate HTR-PM and PWR test-zone leads; owner-direct safety, cost, schedule, quality and test witnesses.
10. Program management, nuclear QA, China licensing support, and independent review	China-based public-interest program office, independent estimator/auditor, nuclear QA/licensing advisers, legal/data-rights support, and advisory panels.

Managing organization versus recipient

The Managing Organization should not routinely compete for the largest technical awards. If it or an affiliate has unique Chinese facilities or data rights, any self-award should be disclosed, independently priced, approved by the Funding Source, and reviewed by a conflict-free panel. The same rule applies to CNNC-, CGN-, university-, or equipment-vendor affiliates: ownership relationships must be visible so that competition between HTR-PM, PWR, common-platform, and conventional-construction options remains credible.

Project Management

Prompt to AI: How should the \$1 billion China-based dual-reference program be managed? Define the funding source, managing organization, program manager, HTR-PM and PWR design authorities, work-package managers, technical authority, advisory panels, decision rights, reporting, cost/schedule control, safety, quality, and transition.

Response From AI:

The program should be an owner-led systems-development effort with one integrated baseline and two controlled reactor-reference branches. The Funding Source (FS) provides money and public-benefit conditions. A China-capable Managing Organization (MO) receives and accounts for funds, employs the owner team, maintains procurement and financial systems, and issues agreements. The Program Manager owns delivery. A Chief Engineer controls the common machine platform and interfaces. Separate HTR-PM and PWR Reference Design Authorities control reactor-specific assumptions and approved construction interfaces. Independent safety, quality, economics, and management panels report to the FS or governing board, not to the contractors they review.

Entity	Primary responsibilities	Authorities and limits
Funding Source / Governing Board	Approve mission, \$1B budget, China implementation, MO, gates, reserve, openness, dual-reference balance, and first-site transition.	Does not direct daily engineering; may pause a reactor track, replace managers, release reserve, or redirect funding toward the better-performing construction path.
Managing Organization	Employ owner team; contracts; accounting; China compliance; data systems; facilities; reporting.	Cannot change mission, favor an affiliated reactor vendor, release major reserve, or self-award conflicted work without approval.
Program Manager	Own integrated delivery, cost, schedule, risk, requirements, pilot, corrective action, and common-platform economics.	Cannot waive nuclear safety, quality, independent review, data-rights, or dual-reference comparison requirements.
Chief Engineer / Common Platform Design Authority	Own machine-system technical baseline, common interfaces, verification, change control, and architecture decisions.	Cannot alter controlled HTR-PM or PWR nuclear interfaces without the applicable reference design authority.
HTR-PM Reference Design Authority	Own HTR-PM construction assumptions, interfaces, loads, tolerances, sequence, and safety-related boundary conditions.	Does not certify common-platform cost/performance or PWR work.
PWR Reference Design Authority	Own Hualong One-class construction assumptions, interfaces, loads, tolerances, sequence, containment/liner and nuclear-island boundaries.	Does not certify common-platform cost/performance or HTR-PM work.
Work-Package Managers	Manage scope, contracts, acceptance, interfaces, cross-track reuse, and risks.	Cannot make unilateral interface changes, hide reactor-specific exceptions, or suppress unfavorable comparisons.

Entity	Primary responsibilities	Authorities and limits
Independent Safety / Quality / Economics Authorities	QA, supplier qualification, pilot safety, hold points, nonconformance, cost/schedule verification, records.	Direct board access and stop-work/withhold-acceptance authority within charter.
Scientific/Engineering + Management/Audit Panels	Technical merit, alternatives, readiness, procurement integrity, cost/schedule, conflicts, reserve, and publication quality.	Advisory except where concurrence is explicitly made a gate condition; cannot override nuclear regulator or safety authority.

Owner-team staffing

Function	Peak staff	Notes
Leadership, reference-design, and work-package management	24-32	Program manager/deputy, chief engineer, HTR-PM and PWR reference leads, ten work-package managers, integration and transition.
Systems engineering / configuration / digital thread	18-28	Requirements, common-vs-specific interfaces, verification, change control, data architecture, model-based construction, records.
Safety, QA, China licensing support, and security	14-22	Independent authority, supplier quality, regulator engagement, pilot safety, cyber/physical security, stop-work.
Contracts, finance, legal, IP, and data rights	12-18	Competition, invoice review, audit, Chinese contracting/IP, controlled vendor data, publication/open access, export controls where applicable.
Cost, schedule, risk, and estimating	10-15	Bottom-up HTR-PM/PWR quantities, integrated master schedule, quantitative risk, estimate-to-complete, site \$/W, LCOE impact, reserve.
Pilot operations / EHS / commissioning oversight	14-24	Two test zones, commissioning, readiness, heavy equipment, emergency planning, incident response, independent witnesses.
Open repository / standards / communication	5-9	Publish permissible machine designs, interface standards, test data, minutes, decisions, cost/schedule methods, and analyses.
Total owner-side peak	97-148	Contractor engineering, factory labor, craft labor, and reactor-vendor personnel are additional.

Monthly management rhythm

1. Contractors report cost, schedule, technical, quality, safety, risk, and data-delivery status against the baseline.
2. Work-Package Managers validate physical progress, not just labor hours.
3. The Chief Engineer reviews interfaces, verification, nonconformance, and configuration drift.
4. The cost/schedule team updates forecast and quantitative schedule risk; material variances trigger recovery plans.
5. The Program Manager publishes an open dashboard with narrow lawful redactions.
6. Independent panels review quarterly and report directly to the board.

Reserve-release test

Each request must state what changed, why it was not in baseline, consequences of doing nothing, alternatives, independent evidence, revised cost/schedule, and accountable manager. Reserve must not conceal weak estimates, unmanaged scope, or poor performance.

Transition to first licensed sites

During Year 4, create two small transition teams: one for an HTR-PM/HTR-PM600-type first site and one for a Hualong One-class PWR first site. Each team should identify the Chinese owner, candidate site envelope, reactor-vendor arrangement, NNSA engagement path, financing, supply chain, machine fleet, and conventional fallback methods. Phase II need not fund both reactor types equally. It should follow the measured evidence: common machines may deploy to both; reactor-specific machines should proceed only where their savings justify qualification and deployment.

Funding Source Requirements

Prompt to AI: What requirements should the funding source impose on a China-based HTR-PM + PWR site-construction-automation program to maximize climate benefit per dollar, reduce waste, ensure nuclear safety and integrity, preserve fair comparison between reactor tracks, and make the construction technology broadly reusable?

Response From AI:

Use “open by default, restricted by written exception,” while recognizing legitimate Chinese nuclear-security, cybersecurity, controlled-design-data, commercial IP, and export-control constraints. The central governance rule is evidence before advocacy: neither HTR-PM nor PWR is preselected as the economic winner. Every major machine and construction change must show measured performance against a conventional Chinese baseline and disclose when a supposedly common solution actually shifts cost or risk elsewhere.

Requirement	Recommended condition
Mission and scope	Spend only on the approved five-year China site-construction-automation mission for HTR-PM and Hualong One-class PWR reference plants; exclude commercial plant construction, reactor physics/fuel R&D, political advocacy, and unrelated facilities.
Two controlled reference baselines	Freeze auditable HTR-PM and PWR construction quantities, sequences, loads, tolerances, safety classifications, site assumptions, conventional labor/equipment baselines, and cost/schedule models before claiming automation savings.
Design maturity before build	Complete requirements, alternatives, common-vs-specific architecture, risk reduction, preliminary design, independent review, and credible cost/schedule baselines before major fabrication.
Controlled exceptions	Use written, indexed exceptions for export control, cybersecurity, physical security, privacy, licensed vendor data, and pre-existing proprietary technology.
Foreground data rights	The fund receives rights to reproduce, modify, manufacture, competitively source, maintain, and transfer technology paid for by the program.
Background IP	Identify background IP before award; explicitly negotiate royalties, field-of-use, source-code access, escrow, transition, and second-source rights.
Independent verification	Safety, quality, precision, cost, schedule, software, and readiness claims are reviewed by organizations not controlled by performers.
Independent verification	Safety, quality, precision, throughput, site \$/W, build-time, software, and readiness claims are reviewed by organizations not controlled by the applicable HTR-PM/PWR performer.
Human-supervised autonomy	Define operating domains, authorization, geofencing, safe stop, intervention, recovery, logging, and cybersecurity; do not assume unattended operation.
No hidden failures	Promptly report and preserve material failures, incidents, near misses, nonconformances, rejected designs, schedule slips, and cost growth.
Milestone payment	Pay for accepted deliverables and demonstrated performance, with holdbacks for data, documentation, training, and final configuration handoff.
Competition and second	Compete early concepts and preserve second-source manufacturing and maintenance

sources	rights for critical equipment.
Conflict management	Disclose institutional and personal conflicts; require recusals and special approval for related-party or managing-organization self-awards.
Cost and schedule transparency	Maintain integrated schedules, risk-adjusted estimates, commitments, invoices, physical progress, forecasts, and a reserve ledger.
Replicability and comparative economics	Every prototype report includes manufacturing cost, operating cost, crew, maintenance, availability, consumables, site needs, learning assumptions, and separate HTR-PM/PWR/conventional-baseline sensitivities.
Common interfaces and deliberate divergence	Prefer common mechanical, electrical, data, lifting, transport, metrology, and records interfaces; document when reactor-specific geometry or safety requirements make a separate solution superior.
Safety and stop-work	Protect stop-work authority; independently investigate incidents; track corrective actions to closure.
Environmental and community safeguards	Review spoil, water, dust, noise, traffic, worker exposure, emergency plans, permitting, and community communication.
International and supply-chain diligence	Screen sanctions, export controls, corruption, forced labor, counterfeit parts, security risk, and single-country dependency.
Phase-gate discipline	The governing board can pause, restructure, reduce, or terminate either reactor track or any machine family at every gate; there is no presumption that all \$1 billion must be spent or split evenly.

Required public repository

Collection	Minimum contents
Program baseline	Mission, requirements, budget, schedule, risk register, organization, decisions, and change log.
Procurement ledger	Solicitations, criteria, awards, statements of work, recipients, amounts, modifications, invoices, and acceptance.
Engineering archive	Native models, drawings, interfaces, calculations, code, bills of material, manufacturing plans, and configuration.
Test archive	Procedures, readiness, calibration, raw/processed data, uncertainty, video, failures, incidents, corrections, and independent reports.
Economics archive	Capital/operating cost, labor, cycles, availability, learning, sensitivity, and independent estimates.
Governance archive	Board/panel membership, conflicts, minutes, gates, reserve releases, audits, corrective actions, and restrictions index.

Climate-benefit metric

Do not claim climate benefit from prototype completion alone. Report the independently estimated reduction in cost and delivery time of standardized 24/7 low-carbon electricity and useful heat, multiplied by plausible Chinese deployment scale and adjusted for technical, licensing, financing, siting, transmission, and adoption risk. Publish HTR-PM and PWR results side by side, including plant-gate and delivered-electricity cases. A safer reactor may have siting/transmission value, but that value should be modeled from regulator-credible site scenarios rather than assumed.

Top 25 Papers

Prompt to AI: Identify and summarize 25 papers, reports, or major references most relevant to a China-based program that automates site construction for both HTR-PM and Hualong One-class PWR plants. Explain why each matters and what it does not establish.

Response From AI:

The list combines HTR-PM safety and construction references, current Hualong One serial-construction and automation evidence, China nuclear-program context, nuclear cost/construction studies, modularization, digital engineering, and heavy-equipment robotics. It is not a systematic review. Before procurement, commission a formal Chinese-language search of NNSA requirements, GB/NB/T standards, CNNC/CGN construction procedures, patents, supplier data, lessons learned, and current project records.

1. Zhang et al., “Design Aspects of the Chinese Modular High-Temperature Gas-Cooled Reactor HTR-PM,” 2006

HTR-PM design lineage and safety concepts; useful for separating reactor-specific systems from construction tasks and defining the passive-safety basis behind the HTR-PM track.

Limitation: Orientation only; not a controlled as-built construction package or evidence that a proposed automated civil layout is licensable.

Reference: <https://inis.iaea.org/>

2. Zhang et al., “Current Status and Technical Description of Chinese 2 x 250 MWth HTR-PM Demonstration Plant,” 2009

Defines representative HTR-PM component sizes, module count, systems, and arrangement needed to bound lifting, excavation, transport, and installation machinery.

Limitation: Predates completion and commercial operation; current controlled design and as-built data should supersede it.

Reference: <https://doi.org/10.1016/j.nucengdes.2009.02.023>

3. Zhang et al., “The Shidao Bay 200 MWe HTR-PM Demonstration Power Plant: An Engineering and Technological Innovation,” 2016

Provides the HTR-PM engineering basis, 250 MWth modules, 567 C steam design, construction history, and multi-module economics discussion relevant to the HTR-PM reference track.

Limitation: Does not validate the Climate Moonshot underground arrangement or a construction-automation cost target.

Reference: <https://www.engineering.org.cn/engi/EN/10.1016/J.ENG.2016.01.020>

4. Zhang et al., “Loss-of-Cooling Tests Validate the Inherent Safety of the World’s First Commercial Small Modular Reactor,” Joule, 2024

Full-scale safety tests support the passive/inherent-safety rationale that motivates evaluating different HTR-PM siting and emergency-planning scenarios.

Limitation: Thermal safety behavior does not itself prove closer siting, lower transmission cost, or lower construction cost; regulators decide site requirements.

Reference: <https://www.sciencedirect.com/science/article/pii/S2542435124002903>

5. Dong et al., “Testing the Multi-Modular Design and Inherent Safety Features of a Commercial Nuclear Power Plant,” Nature Communications, 2025

Peer-reviewed evidence on multi-module HTR-PM operation and safety behavior; relevant to repeated-module construction and the case for industrial heat.

Limitation: Does not establish automated construction economics or the licensing of new civil arrangements.

Reference: <https://www.nature.com/articles/s41467-025-58194-7>

6. CNNC, “The Hualong One: China’s Solution for the Global Clean Energy Transition,” 2025

Primary industry reference for the Hualong One serial-build program, supply chain, standardized deployment, and unit scale; useful for selecting the PWR reference plant.

Limitation: Promotional/owner material; independent cost and schedule verification remains necessary.

Reference: https://en.cnn.com.cn/2025-05/12/c_1091926.htm

7. CNNC, “Fuqing Nuclear Power Surpasses 400 Billion kWh,” 2026

Documents the first Hualong One construction duration of 68.7 months and the continuing emphasis on standardization and digital intelligence; useful as a real Chinese schedule baseline.

Limitation: A first-of-a-kind record does not by itself establish the schedule of later units or the savings from the proposed automation program.

Reference: https://en.cnn.com.cn/2026-06/01/c_1187358.htm

8. CGN, “Taipingling Unit 2 Achieves First Grid Connection and Power Generation,” 2026

Shows current Hualong One construction already using smart construction systems, modularization, automatic welding, integrated hoisting, digital handover, and robots; the fund should extend rather than duplicate this work.

Limitation: Company reporting does not quantify the counterfactual cost or schedule without each technology; the program must instrument and independently audit those effects.

Reference: https://en.cgnpc.com.cn/encgn/pressReleases/2026-07/21/content_44c301fbe6d744c3b880896edc8c5442.shtml

9. IAEA, China Country Nuclear Power Profile / PRIS, 2026

Provides authoritative context on the scale of China’s operating and under-construction nuclear fleet, supporting the premise that a reusable machine fleet could have many deployment opportunities.

Limitation: Fleet counts and program context do not prove any particular reactor design or construction machine is economic.

Reference: <https://cnpp.iaea.org/public/countries/CN/profile/highlights>

10. MIT, “The Future of Nuclear Energy in a Carbon-Constrained World,” 2018

Identifies construction cost, design maturity, owner capability, standardization, and project delivery as central barriers to lower nuclear cost.

Limitation: Broad recommendations do not validate this dual-reference machine portfolio or its budget.

Reference: <https://energy.mit.edu/wp-content/uploads/2018/09/The-Future-of-Nuclear-Energy-in-a-Carbon-Constrained-World.pdf>

11. OECD Nuclear Energy Agency, “Reducing the Costs of Nuclear Power,” 2020

Framework for cost drivers across design, regulation, financing, supply chain, repeat build, project governance, and construction.

Limitation: Automation is one lever; financing, design changes, weak owner capability, or poor regulation can erase construction savings.

Reference: https://www.oecd-nea.org/jcms/pl_37787/

12. Energy Technologies Institute, “The ETI Nuclear Cost Drivers Project,” 2018

Evidence on repeat build, mature design, owner capability, contracting, productivity, and supply-chain conditions associated with lower cost.

Limitation: UK-focused evidence must be translated carefully to Chinese labor, supply chain, regulation, and serial construction.

Reference: <https://es.catapult.org.uk/report/nuclear-cost-drivers/>

13. EPRI, “Economics-Based R&D Roadmap for Nuclear Power Plant Construction,” 2019

A useful model for prioritizing construction R&D by measurable economic leverage and stage-gating rather than technological novelty alone.

Limitation: Does not prescribe the HTR-PM/PWR allocation or prove a specific machine will save money.

Reference: <https://gain.inl.gov/gain-epri-neis-workshop-about-economics-based-rd-for-nuclear-power-construction/>

14. IAEA, “Construction Technologies for Nuclear Power Plants,” 2011

Established practices in modularization, heavy lifting, prefabrication, concrete, planning, inspection, commissioning interfaces, and quality control.

Limitation: Current Chinese codes, Hualong One practices, autonomy, digital twins, and modern equipment must supplement it.

Reference: https://www-pub.iaea.org/MTCD/Publications/PDF/P1526_Web.pdf

15. U.S. NRC, “Application of Advanced Construction Technologies to New Nuclear Power Plants,” 2004

Useful regulatory reasoning on inspectability, traceability, design control, modular construction, advanced concrete, and acceptance evidence.

Limitation: U.S. regulatory guidance is not Chinese licensing law and predates modern field robotics and digital construction.

Reference: <https://www.nrc.gov/docs/ml0931/ml093160836.pdf>

16. Wrigley et al., “Off-Site Modular Construction and Design in Nuclear Power,” 2021

Explains benefits and limits of factory fabrication, transport, lifting, tolerance, inspection, rework, and module interfaces.

Limitation: Larger or more factory-complete modules are not automatically cheaper; transport and connection complexity can offset gains.

Reference: <https://www.sciencedirect.com/science/article/abs/pii/S0149197021000354>

17. Lloyd, “Modular Manufacture and Construction of Nuclear Power Plants,” Cambridge, 2020

Detailed treatment of modularization strategy, organizational interfaces, manufacturing, transport, installation, and learning.

Limitation: A thesis is not a Chinese code, vendor commitment, or qualification record.

Reference: <https://www.repository.cam.ac.uk/items/9b1eacd3-a74e-46fd-ba3c-e4f96df7bafb>

18. NRIC, “Advanced Construction Technology Initiative Final Design Review Report,” 2024

Modern precedent for full-scale non-nuclear nuclear-construction demonstrations, factory/site integration, and digitally documented test articles.

Limitation: Uses different structural systems and regulatory context; results cannot simply be copied to HTR-PM or Hualong One.

Reference: <https://nric.inl.gov/content/uploads/34/2024/11/RPT-24-79427-Rev-0-ACTI-Final-Design-Review-Report-1.pdf>

19. Kropaczek et al., “Digital Twins for Nuclear Power Plants and Facilities,” 2023

Connects engineering models, data, uncertainty, configuration, and decision support; relevant to an auditable construction digital thread.

Limitation: A digital twin creates false confidence if inputs, calibration, configuration control, and verification are weak.

Reference: <https://impact.ornl.gov/en/publications/digital-twins-for-nuclear-power-plants-and-facilities/>

20. Bhardwaj and Varma, AISC Design Guide 32, 2017

Modular steel-plate composite structural methods provide a competing path to reduce formwork and rebar labor in nuclear structures and should be compared with conventional reinforced concrete.

Limitation: A structural method must satisfy the applicable Chinese design, seismic, fire, durability, fabrication, inspection, and licensing requirements.

Reference: <https://www.aisc.org/>

21. Zhang et al., “An Autonomous Excavator System for Material Loading Tasks,” Science Robotics, 2021

Shows sustained autonomous operation of full-size heavy equipment using perception, planning, and control, directly relevant to bounded site automation.

Limitation: Open-pit material loading is less constrained than nuclear excavation, precision finishing, lifting, and QA-controlled work.

Reference: <https://www.science.org/doi/10.1126/scirobotics.abc3164>

22. Sotiropoulos et al., “Autonomous Excavation of Rocks,” 2020

Addresses uncertain rock contact, estimation, planning, and force-aware control relevant to excavation and precision finishing.

Limitation: Requires scale-up to maintainable, high-throughput, dust/water-tolerant industrial machinery with nuclear construction records.

Reference:

https://dspace.mit.edu/bitstream/handle/1721.1/128005/ICRA_2020___Automated_rock_scooping.pdf?isAllowed=y&sequence=2

23. Tan et al., “Development and Field Evaluation of a Rebar-Tying Robot,” 2024

Demonstrates progress automating repetitive reinforcing-steel work, a major labor target in both HTR-PM linings and PWR basemats/containments.

Limitation: Dense nuclear reinforcement, embedments, congestion, weld/tie rules, access, tolerances, and inspection require separate qualification.

Reference: <https://www.sciencedirect.com/science/article/abs/pii/S0921889024002100>

24. Zhao et al., “Autonomous Robots in Concrete Construction: A Review,” 2022

Catalogs robotic placement, printing, finishing, inspection, and sensing methods that can inform the concrete work packages.

Limitation: Most examples are not nuclear-grade, heavily reinforced, seismically qualified, or operated under Chinese nuclear QA.

Reference: <https://www.mdpi.com/2504-446X/6/12/424>

25. Yasutomi et al., “Dual-Arm Construction Robot for Large-Scale Assembly,” 2024

Relevant to remote manipulation, fit-up, bolting, tool use, and assembly in constrained construction spaces.

Limitation: The program should use conventional mechanization whenever it is more reliable, maintainable, inspectable, and economic than general-purpose robotics.

Reference: <https://arxiv.org/abs/2403.19948>

Top Researchers and Organizations

Prompt to AI: Who are leading or especially relevant organizations, vendors, laboratories, construction groups, and experts for a China-based HTR-PM + Hualong One site-construction automation program? Group them by capability and explain their potential role.

Response From AI:

No single organization covers the mission. The fund needs HTR-PM authorities, Hualong One/PWR design and serial-construction teams, Chinese nuclear civil contractors, heavy-equipment manufacturers, tunneling specialists, structural and concrete researchers, roboticists, digital/metrology teams, nuclear QA and licensing expertise, independent reviewers, and megaproject managers. “Top” means relevant to the proposed work, not an objective global ranking. The strongest program will combine Chinese deployment authority with independent engineering challenge.

Capability	Illustrative organizations	Potential role
HTR-PM reference	Tsinghua INET; China Huaneng; Chinergy; CNNC; Shanghai Electric	Reference design, safety boundaries, component interfaces, operating/construction experience, design-data access, HTR-PM600 assumptions.
Hualong One / PWR reference	CNNC; CNPE; CNNP; CGN; CGN Engineering; major Chinese nuclear equipment suppliers	Reference construction model, serial-build lessons, containment/nuclear-island interfaces, component loads, modularization, automatic welding, commissioning boundaries.
Nuclear civil construction	China Nuclear Industry Huaxing Construction; qualified CNNC/CGN construction organizations; POWERCHINA Nuclear Engineering; major civil contractors	Nuclear basemats, containments, rebar/concrete, steel liners, modular structures, heavy installation, QA, constructability and site delivery.
Excavation and heavy machinery	China Railway Engineering Equipment Group; XCMG; SANY; LiuGong; Zoomlion; specialized shaft/tunnel suppliers	Rock/soil excavation, cutters, loaders, cranes, concrete equipment, autonomous heavy machines, wear systems, manufacturing scale, maintainability.
Construction robotics and autonomy	Tsinghua; Tongji; Zhejiang; Shanghai Jiao Tong; HIT; CAS institutes; OEM robotics teams	Perception, supervisory autonomy, force control, robotized rebar/concrete/finishing, remote operation, safety cases, human-machine interaction.
Heavy transport and lifting	XCMG; SANY; Zoomlion; CRRC; ZPMC; Chinese heavy-transport specialists	Gantry/cranes, synchronized moves, rail/SPMT systems, route engineering, rigging, proof testing, precision placement.
Structures, concrete, liners, NDE	Tongji/Tsinghua structural groups; Huaxing; CSCEC/MCC capabilities; steel fabricators; NDE laboratories	Full-scale structural tests, concrete/rebar automation, PWR liners, weld/NDE qualification, seismic/constructability review.
Digital engineering / metrology	Huawei and qualified industrial ICT providers; SUPCON/HollySys; metrology vendors; Chinese universities; international	BIM/4-D, digital twins, industrial networks, machine guidance, configuration, reality capture, PLM, as-built verification and cyber

Capability	Illustrative organizations	Potential role
	software vendors where permitted	controls.
Independent integration / economics / audit	Independent Chinese universities and test institutes; independent cost/schedule specialists; international peers where permitted	System integration, full-scale test witnessing, cyber/QA audit, cost/schedule verification, gate review, failure investigation and public-interest administration.

Researchers relevant to review or panel formation

Person / role	Focus	Why relevant
Zuoyi Zhang or Tsinghua INET representative	HTR-PM technical authority	HTR-PM design, multi-module safety, operating experience, industrialization, and access to authoritative interfaces.
Senior Hualong One design authority nominated by CNNC/CNPE	PWR design authority	Hualong One nuclear-island design, construction interfaces, modularization boundaries, safety classifications, and serial-build changes.
Senior Hualong One construction authority nominated by CGN Engineering or equivalent	PWR project delivery	Direct experience with current Hualong One modularization, automatic welding, integrated lifting, smart construction sites, digital handover, and field productivity.
Jacopo Buongiorno	Nuclear systems and economics	Nuclear energy systems, safety, economics, project delivery, and independent comparison of reactor/construction pathways.
Koroush Shirvan	Reactor economics and licensing	Advanced-reactor cost, design, licensing, deployment, and bottom-up economic challenge.
Amit Varma	Nuclear structural systems	Large-scale nuclear structures, modular composite construction, concrete, steel modules, testing, and constructability.
Martin Fischer	Digital construction and project delivery	4-D modeling, virtual design and construction, schedule integration, digital work packaging, and project performance.
Vineet Kamat	Construction robotics	Autonomous systems, simulation, machine safety, field deployment, and human-supervised construction automation.
Carl Haas	Construction automation and productivity	Automation, modularization, productivity measurement, work packaging, and infrastructure construction.
Mani Golparvar-Fard	Reality capture and digital verification	Computer vision, progress measurement, as-built comparison, and construction digital twins.
Senior Chinese tunneling/heavy-equipment automation expert	Excavation and machinery	High-throughput excavation, machine reliability, maintainability, manufacturing scale, and autonomous heavy equipment in Chinese conditions.
Independent Chinese nuclear QA / regulation expert	Safety, QA, licensing	Chinese nuclear construction QA, regulator expectations, hold points, records, nonconformance, and qualification without vendor conflicts.

Selection principles

- Compete defined deliverables rather than preselect one reactor vendor, EPC, equipment OEM, university, or state-owned consortium.
- Require credible paths to both HTR-PM and Hualong One design data and Chinese nuclear requirements; brand name is not data access.
- Fund competing early concepts, then down-select by full-scale physical tests, lifecycle economics, schedule effect, quality, safety, maintainability, and independent review.
- Do not give an HTR-PM vendor, PWR vendor, EPC, equipment prime, or program manager unilateral control of requirements, selection, review, cost model, and data.
- Include operators, craft workers, maintainers, inspectors, construction planners, NDE staff, logistics personnel, owners, and regulators in reviews.

Scientific and Engineering Advisory Panel

Prompt to AI: If a scientific and engineering panel were established for the China HTR-PM + PWR construction-automation fund, who or what roles might serve, what expertise should be represented, and how should the panel operate?

Response From AI:

The panel should be small enough to deliberate, broad enough to challenge both reactor tracks, and independent enough to report uncomfortable findings. The China program needs direct HTR-PM and Hualong One expertise, but vendor representatives should not dominate. Names and roles below are illustrative; availability, employer approval, Chinese confidentiality/security rules, data access, nationality restrictions, and conflicts require confirmation. Comparable substitutes are acceptable.

Person / role	Focus	Why relevant
Zuoyi Zhang or Tsinghua INET representative	HTR-PM technical authority	HTR-PM design, multi-module safety, operating experience, industrialization, and access to authoritative interfaces.
Senior Hualong One design authority nominated by CNNC/CNPE	PWR design authority	Hualong One nuclear-island design, construction interfaces, modularization boundaries, safety classifications, and serial-build changes.
Senior Hualong One construction authority nominated by CGN Engineering or equivalent	PWR project delivery	Direct experience with current Hualong One modularization, automatic welding, integrated lifting, smart construction sites, digital handover, and field productivity.
Jacopo Buongiorno	Nuclear systems and economics	Nuclear energy systems, safety, economics, project delivery, and independent comparison of reactor/construction pathways.
Koroush Shirvan	Reactor economics and licensing	Advanced-reactor cost, design, licensing, deployment, and bottom-up economic challenge.
Amit Varma	Nuclear structural systems	Large-scale nuclear structures, modular composite construction, concrete, steel modules, testing, and constructability.
Martin Fischer	Digital construction and project delivery	4-D modeling, virtual design and construction, schedule integration, digital work packaging, and project performance.
Vineet Kamat	Construction robotics	Autonomous systems, simulation, machine safety, field deployment, and human-supervised construction automation.
Carl Haas	Construction automation and productivity	Automation, modularization, productivity measurement, work packaging, and infrastructure construction.
Mani Golparvar-Fard	Reality capture and digital verification	Computer vision, progress measurement, as-built comparison, and construction digital twins.
Senior Chinese tunneling/heavy-equipment automation	Excavation and machinery	High-throughput excavation, machine reliability, maintainability, manufacturing scale, and autonomous heavy equipment in Chinese conditions.

Person / role	Focus	Why relevant
expert		
Independent Chinese nuclear QA / regulation expert	Safety, QA, licensing	Chinese nuclear construction QA, regulator expectations, hold points, records, nonconformance, and qualification without vendor conflicts.

Panel charter

- Review HTR-PM and PWR reference assumptions, common-versus-specific machine architecture, alternatives, tests, safety/quality, cost/schedule, data, siting/transmission analysis, and gate readiness.
- Require written management responses and track closure; publish permissible findings and dissent while protecting controlled Chinese nuclear and commercial information.
- Meet quarterly plus major design/test reviews; receive direct access to permissible data, contractors, pilot facilities, cost/schedule models, failures, and the governing board.
- Maintain a conflict register; require recusal when members are affiliated with CNNC, CGN, HTR-PM vendors, equipment suppliers, bidders, or organizations under review.
- Do not substitute for the licensed design authority, Chinese regulator, owner, construction QA authority, or site safety authority.

Standing subcommittees

Subcommittee	Expertise	Key reviews
Reactor references and nuclear safety	HTR-PM/HTGR; Hualong One/PWR; safety; plant systems; China licensing	Reference boundaries, controlled data, safety classifications, common-platform interfaces, siting assumptions, first-site gaps.
Civil, structural, and underground	Geotechnical, shafts/tunnels, basemats, containments, seismic, concrete, liners, temporary works	HTR-PM excavations/linings; PWR basemat/containment/liner; materials, tolerances, durability, constructability and qualification.
Machines, logistics, and heavy handling	Construction/mining equipment, cranes, rail/SPMT, autonomy, functional safety, maintenance	Machine concepts, operating domains, proof loads, throughput, failure recovery, commonality, maintainability, factory-to-site logistics.
Digital, metrology, and quality	Digital twins, machine controls, software V&V, reality capture, configuration, NDE, nuclear QA	Data architecture, validation, cybersecurity, metrology, material traceability, as-built evidence, nonconformance and acceptance.
Economics, schedule, siting, and deployment	Cost engineering, Chinese project delivery, financing, supply chain, transmission, multi-unit deployment	Baseline fairness, site \$/W, build time, total CAPEX/LCOE effect, delivered cost, learning, replication, climate impact and Phase II decisions.

Management Advisory Panel

Prompt to AI: If a separate management panel oversaw the agreement between the Funding Source and the China-capable Managing Organization, who or what roles might serve and what should it review?

Response From AI:

Technical excellence does not prevent cost growth, procurement failure, conflicts, weak controls, affiliated-company favoritism, or a manager protecting its institution rather than the mission. A separate management panel or governing-board audit committee should oversee the Managing Organization. Because the program is in China and may involve major state-owned nuclear and construction enterprises, the panel should emphasize transparent work-package accounting, related-party disclosure, independent acceptance, data rights, and a documented basis for allocating funds between HTR-PM, PWR, and common-platform work.

Illustrative member / role	Contribution	Background
Independent chair - retired Chinese megaproject or nuclear executive	Program oversight	Direct responsibility for major nuclear/infrastructure delivery; no current employment by a major technical bidder.
Former Chinese nuclear-regulatory / nuclear-safety leader	Nuclear governance	Experience with NNSA/MEE expectations, nuclear safety culture, licensing interfaces, construction QA, and independence.
Major R&D-program governance expert	Portfolio management	Experience managing large government, academy, university, or industrial R&D portfolios with stage gates and measurable deliverables.
Independent finance / audit leader	Financial controls	Large-program accounting, internal controls, related-party transactions, reserve governance, forensic audit, and corrective action.
Public procurement / contracting expert	Competition and supplier management	Chinese procurement, tender evaluation, cost/price analysis, contract remedies, data rights, and second sourcing.
Independent nuclear construction executive	Construction delivery	Retired HTR-PM/PWR, tunneling, heavy lift, concrete, rail, or power-construction leader with billion-dollar project experience.
Open technology / IP / standards expert	Replication and access	Chinese and international IP, standards, licensing, source-code/data rights, foreground/background technology, and controlled openness.

Responsibilities

Review area	Questions
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Review area	Questions
MO performance	Is the manager recruiting qualified China staff, administering procurements fairly, controlling the dual-reference baseline, paying correctly, enforcing terms, and supporting the mission?
Cost/schedule	Are HTR-PM and PWR conventional baselines credible? Is physical progress verified? Are common-platform savings double-counted? Is reserve used for true risk?
Procurement integrity	Were competitions documented? Are sole-source awards justified by design rights or unique facilities? Are affiliated bidders treated transparently?
Conflicts/self-dealing	Is work steered to an MO affiliate, reactor vendor, state-owned parent, panel member, donor, or favored institute without objective basis? Are recusals complete?
Data rights/openness	Is the program receiving promised machine designs, software, test data, cost/schedule evidence, and manufacturing/maintenance rights while respecting controlled reactor data?
Safety/quality governance	Do independent authorities have resources, access, hold-point power, stop-work authority, and direct escalation channels?
Audit/corrective action	Are financial, technical, cyber, nuclear-QA, procurement, and compliance audits timely? Are failures and corrective actions tracked to closure?
Succession	Can leaders, the MO, or a major contractor be replaced without losing data, pilot assets, machine control, contracts, or continuity?

[Escalation rights](#)

The panel should report directly to the Funding Source, recommend withholding funds, request independent investigation, require corrective action, recommend replacing the Managing Organization, or recommend pausing one reactor track when the evidence no longer supports it. It should not direct daily engineering or override the Chinese regulator, licensed design authority, or independent safety/quality authority.

Agreements

Prompt to AI: What might the agreement between the Funding Source and Managing Organization look like, and what might the agreement between the Managing Organization and a China-based purchase-order recipient look like for this dual HTR-PM + PWR construction-automation program? Provide practical term-sheet language, not a jurisdiction-specific final contract.

Response From AI:

These are planning term sheets, not legal advice or complete Chinese contracts. Final agreements must reflect party identities, Chinese law, tax status, public/private funding, nuclear law and NNSA requirements, cybersecurity and state-secrets rules, procurement, labor, environmental requirements, insurance, IP ownership, controlled reactor-vendor data, import/export controls, and any international collaboration restrictions. The agreements should preserve a fair HTR-PM/PWR comparison while preventing sponsor-funded construction technology from becoming unnecessarily locked to one reactor vendor.

Agreement A: Funding Source to Managing Organization

Term	Recommended provision
Purpose and restricted use	Use funds only for the approved China HTR-PM + PWR site-construction-automation program, authorized procurements, dual-track pilot, and agreed administration; return unused or disallowed funds.
Term and funding tranches	Five-year term with annual or gate-based tranches; later tranches and reserve releases depend on approved baselines, performance, audit, and gate decisions.
Program plan and budget	Incorporate the two reference construction baselines, common-platform strategy, work packages, budget, schedule, governance, success criteria, exclusions, comparative economics, and change control.
Governance and appointments	FS approves Program Manager, Chief Engineer, independent safety/quality authority, panel chairs, and material replacements.
Decision rights	MO manages daily execution; FS approves mission changes, material shifts between HTR-PM/PWR/common-platform work, large reallocations, reserve releases, major sole sources, conflicted self-awards, and Phase II.
Procurement standards	Fair documented competition, written evaluation, price/cost analysis, conflict controls, and flow-down of mission, data, safety, quality, audit, and open-access terms.
Financial controls	Separate project ledger, dual approvals, commitment control, invoice validation, monthly reports, annual audit, and FS/auditor access.
Overhead and fee	State allowable indirect cost, fee, and administrative support; prohibit hidden markup, pass-through profit, and double charging.
Technical and data rights	FS receives ownership or broad irrevocable rights in sponsor-funded foreground construction-machine results for use, modification, manufacture, competition, maintenance, and transfer, subject to negotiated protection of controlled reactor-vendor background data.

Open publication	Publish permissible results on schedule; withholding requires written legal, safety, security, privacy, export-control, or pre-approved background-IP basis.
Nuclear QA, safety, and security	Establish graded nuclear QA, independent safety authority, stop-work, cyber/physical security, incident reporting, and regulator engagement.
Records and transparency	Retain procurement, finance, engineering, test, quality, safety, conflicts, and governance records; provide FS read access and public index.
Conflicts and related parties	Disclose conflicts, prohibit gifts and contingent influence, require recusals, and obtain FS approval for related-party or MO self-awards.
Key-person and succession	Identify key staff, commitment, replacement qualifications, transition support, and removal rights for performance or integrity.
Performance and remedies	Use milestones, acceptance, corrective action, payment withholding, recompetition, step-in, suspension, termination, repayment, and damages where appropriate.
Independent review and audit	FS and panels get direct access to contractors, facilities, data, meetings, and records; MO responds to findings and tracks closure.
Liability and insurance	Allocate pilot-site, equipment, professional, cyber, environmental, worker, and third-party risks; state insurance and lawful caps.
Termination and transition	FS may terminate for convenience or cause; MO preserves work, transfers contracts/data/equipment, assists successor, and prevents lock-in.
Disputes and law	Define executive escalation, mediation/arbitration or courts, governing law, venue, and continued safe performance during disputes.

Agreement B: Managing Organization to Purchase-Order Recipient

Term	Recommended provision
Statement of work	Define HTR-PM, PWR, or common-platform scope; assumptions; exclusions; interfaces; deliverables; quantities; China locations; performance; standards; and responsibility matrix.
Technical baseline	Incorporate the applicable HTR-PM/PWR reference requirements, drawings, controlled interfaces, configuration, operating domain, safety classification, software baseline, and acceptance criteria.
Milestones and schedule	Use resource-loaded schedule linked to reviews, long-lead procurement, fabrication, factory tests, pilot installation, demonstration, and handoff.
Pricing and payment	Choose fixed-price, cost-reimbursement, or hybrid form; define allowable costs, fee, ceilings, invoices, retainage, and milestone acceptance.
Reviews and hold points	No advancement past hold points without written approval; close or formally disposition all findings.
Quality and suppliers	Apply graded nuclear QA; control subtiers, materials, calibration, software, welds, concrete, NDE, nonconformance, counterfeit parts, and records.
Safety and environment	Comply with site rules, hazard analysis, permits, exposure controls, emergency plans, stop-work, incident/near-miss reporting, and correction.
Testing and acceptance	Specify proof loads, precision, throughput, availability, failure tests, HTR-PM/PWR test configuration, baseline comparison, data completeness, independent witnesses, deficiencies, and retest obligations.
Testing and acceptance	Specify proof loads, precision, throughput, availability, failure tests, data completeness, independent witnesses, deficiencies, and retest obligations.
Intellectual property	Identify reactor-vendor and equipment-vendor background IP before award; state patent, copyright, source-code, manufacturing, sublicense, escrow, spare-parts, maintenance, and second-source rights for sponsor-funded foreground technology.

Intellectual property	Identify background IP before award; state patent, copyright, source-code, manufacturing, sublicense, escrow, and second-source rights.
Open publication	Permit prompt publication after narrow legal/security review; prohibit clauses intended mainly to suppress failures or unfavorable comparisons.
Personnel and facilities	Identify key personnel, qualifications, secure facilities, special equipment, pilot access, and substitution rules.
Subcontracting	Require consent for major subcontracts, competition where appropriate, flow-down terms, conflict disclosure, data rights, and audit access.
Reporting	Monthly physical progress, commitments, actuals, forecast, schedule, risks, changes, nonconformance, and corrective action.
Changes	Only authorized changes alter scope, price, schedule, or baseline; unauthorized work proceeds at contractor risk.
Warranties and support	Define design/workmanship, software, spares, defect correction, field support, reliability growth, obsolescence, and training.
Audit and access	MO, FS, safety/quality authorities, and independent reviewers may inspect work, records, facilities, suppliers, tests, and data.
Suspension and termination	Rights for safety, quality, security, nonperformance, loss of funds, convenience, insolvency, corruption, sanctions, or withheld data.
Disputes and claims	Early notice, documented claim/change process, continued safe performance, executive escalation, and final forum.

Example milestone payment

Milestone	Payment	Evidence
Award and approved plans	5%	Baseline schedule; quality, safety, data, configuration, insurance, and required bonds.
Requirements review	10%	Approved requirements, interfaces, hazards, acceptance plan, and updated estimate.
Preliminary design review	15%	Controlled design, risk tests, independent findings, and closure plan.
Critical design/build authorization	15%	Detailed drawings, bills, suppliers, manufacturing readiness, and safety case.
Fabrication complete	20%	Conforming hardware, material records, inspections, software baseline, and factory readiness.
Factory acceptance	15%	Test results, deficiencies, corrected configuration, and installation plan.
Pilot demonstration	15%	Independent HTR-PM/PWR performance, safety/quality, reliability, baseline comparison, accepted deficiencies, and cost/schedule evidence.
Final data handoff	5%	Native files, code, data, manuals, training, spares, licenses, and audit closure.

Further Reading

Prompt to AI: Provide a concise further-reading and source list for the dual China HTR-PM + PWR construction-automation fund, separating user-provided material from external technical references and emphasizing primary Chinese sources where available.

Response From AI:

Primary user-provided source material

The fund concept, HTR-PM underground arrangement, gantry, railcars, excavation, concrete, and module-placement illustrations are based on the user-provided Climate Moonshot Business Plan and the prior HTR-PM construction-automation proposal. The revised fund adds a Hualong One-class PWR reference track while preserving the document structure and formatting system.

- Climate Moonshot Business Plan, especially “Nuclear Power Climate Strategy,” “Automate Nuclear Power Construction,” and “Co-locate Chemical Processing with Nuclear Power” ([google drive](#)).
- Proposed \$1B SAI Equipment Development Fund — User-provided Word document ([google drive](#))
- Formatting instructions and gsw_research_fund_template_v4 — User-provided instruction and template files ([google drive](#)).

China reference reactors and current construction practice

- HTR-PM engineering and technological innovation (Engineering, 2016) — <https://www.engineering.org.cn/engi/EN/10.1016/J.ENG.2016.01.020>
- HTR-PM loss-of-cooling safety tests (Joule, 2024) — <https://www.sciencedirect.com/science/article/pii/S2542435124002903>
- HTR-PM multi-module testing (Nature Communications, 2025) — <https://www.nature.com/articles/s41467-025-58194-7>
- CNNC: The Hualong One - China’s clean-energy reference design — https://en.cnncc.com.cn/2025-05/12/c_1091926.htm
- CNNC: Fuqing Hualong One construction duration and standardization — https://en.cnncc.com.cn/2026-06/01/c_1187358.htm
- CGN: Taipingling Hualong One digitalization, modularization and automatic welding — https://en.cgnpc.com.cn/encgn/pressReleases/2026-07/21/content_44c301fbe6d744c3b880896edc8c5442.shtml
- IAEA: China Country Nuclear Power Profile / PRIS — <https://cnpp.iaea.org/public/countries/CN/profile/highlights>

Nuclear construction, cost, modularization, and digital engineering

- MIT: The Future of Nuclear Energy in a Carbon-Constrained World — <https://energy.mit.edu/wp-content/uploads/2018/09/The-Future-of-Nuclear-Energy-in-a-Carbon-Constrained-World.pdf>
- OECD NEA: Reducing the Costs of Nuclear Power — https://www.oecd-neo.org/jcms/pl_37787/
- Energy Technologies Institute: Nuclear Cost Drivers — <https://es.catapult.org.uk/report/nuclear-cost-drivers/>
- IAEA: Construction Technologies for Nuclear Power Plants — https://www-pub.iaea.org/MTCD/Publications/PDF/P1526_Web.pdf
- U.S. NRC: Application of Advanced Construction Technologies — <https://www.nrc.gov/docs/ml0931/ml093160836.pdf>
- NRIC: Advanced Construction Technology Initiative — <https://nric.inl.gov/content/uploads/34/2024/11/RPT-24-79427-Rev-0-ACTI-Final-Design-Review-Report-1.pdf>
- EPRI/GAIN: Economics-Based R&D for Nuclear Power Construction — <https://gain.inl.gov/gain-epri-neis-workshop-about-economics-based-rd-for-nuclear-power-construction/>
- Digital twins for nuclear facilities — <https://impact.ornl.gov/en/publications/digital-twins-for-nuclear-power-plants-and-facilities/>

Robotics and automated construction

- CNNC: New robots debut in nuclear power construction — https://en.cnn.com.cn/2026-06/01/c_1187366.htm
- Autonomous excavator system — <https://www.science.org/doi/10.1126/scirobotics.abc3164>
- Autonomous rock excavation — https://dspace.mit.edu/bitstream/handle/1721.1/128005/ICRA_2020_Automated_rock_scooping.pdf?isAllowed=y&sequence=2
- Development and field evaluation of a rebar-tying robot — <https://www.sciencedirect.com/science/article/abs/pii/S0921889024002100>
- Robots in concrete construction review — <https://www.mdpi.com/2504-446X/6/12/424>
- Dual-arm construction robot for large-scale assembly — <https://arxiv.org/abs/2403.19948>

Final note

This is a proposed R&D portfolio. Budgets, recipients, economic targets, and agreements are illustrative and require independent review before funds are committed. Unlike the prior HTR-PM-only proposal, this program develops a common automation platform against both HTR-PM and a standardized Chinese PWR, measures where machines transfer between them, and lets full-scale cost, schedule, quality, and safety evidence determine deployment.

Initial Prompt to AI

Prompt to AI: Enclosed is a \$1B proposal to automate the construction of a nuclear power plant ("nuclear_power_automate_construction_fund, v1e.docx"). Change it so that the \$1B program develops machines that automate site construction for both HTR-PM and a PWR similar to standardized Hualong One-class plants built in China. Assume the program and deployment context is China.

I want the new Microsoft Word file in a format similar to "nuclear_power_automate_construction_fund, v1e.docx", with one chapter per prompt to AI.

Use "Instructions for file formatting.docx" for the formatting rules and

"gsw_research_fund_template_v4.dotx" for reference on fonts and styles.

Apply the table-header/body/table styles consistently. Do not insert an empty paragraph or row before or after tables, and use zero paragraph spacing immediately before and after each table.

Preserve the prior proposal's structure, figures, governance, procurement logic, and evidence-based stage gates where useful, while rewriting technical content so the fund supports both reactor reference plants rather than HTR-PM alone.

After formatting the final .docx file, allow me to download it.

Response From AI:

Created this file.