

Nuclear Repowering Interface Architecture (NRIA): Standardizing Nuclear Repowering

A Three-Point Framework for Classifying Turbines, Heat Output and Interface Architectures

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Technical Sections

1. Introduction

Nuclear repowering is the conversion of an existing fossil-fuel power plant to nuclear heat while retaining, to the greatest practical extent, the existing steam turbine and conventional power island.

The principal challenge in developing a repeatable repowering framework is that existing turbines are not identical. They operate across a range of steam pressures and temperatures, while different nuclear heat sources and integration arrangements provide fundamentally different thermal configurations.

If every combination is treated as a unique engineering problem, nuclear repowering remains inherently bespoke.

A standardized approach requires the opposite: **a finite set of classifications and a finite set of allowable combinations.**

The Nuclear Repowering Interface Architecture (NRIA) establishes this through a simple three-point structure:

END 1	INTERMEDIATE	END 2
Envelope Family (EF)	Interface Architecture Class (IAC)	Heat Output Class (HOC)
What is the existing turbine?	How is the nuclear heat integrated?	What class of heat output is being considered?

Within the intermediate point, each IAC has a defined **Interface Boundary Point (IBP)** that establishes the physical separation between the Nuclear Domain and the Non-Nuclear Domain.

The resulting framework is therefore:

EF — IAC/IBP — HOC

The purpose is not to prescribe a particular reactor, turbine modification or project design. It is to establish a **common language and a finite compatibility space** within which nuclear repowering can be classified.

2. End 1 — Classifying the Existing Turbine

The starting point is the existing steam turbine.

A repowering project inherits the thermodynamic characteristics of that turbine. NRIA therefore classifies existing turbines according to their original certified design conditions rather than treating each turbine as a unique case.

Four standardized **Envelope Families (EFs)** are defined. The classification uses the turbine's certified main steam pressure, main steam temperature and hot reheat temperature.

Table 1 — Envelope Families

Envelope Family	Main Steam Pressure	Main Steam Temperature	Hot Reheat Temperature	Typical Classification
EF-1	≤ 18.0 MPa	≤ 541°C	≤ 541°C	Subcritical / older fleets
EF-2	18.1–26.9 MPa	542–582°C	542–582°C	Modern subcritical / low-end supercritical
EF-3	≥ 27.0 MPa	583–624°C	≥ 583°C	Ultra-supercritical fleets
EF-4	≥ 27.0 MPa	≥ 625°C	≥ 600°C	Advanced USC / next-generation systems

The EF is therefore a classification of the **existing turbine envelope**. It is not a classification of the nuclear technology.

The framework deliberately limits the number of categories to four. Additional project-specific turbine categories would reintroduce the very bespoke classification that the standard is intended to eliminate. Final EF Section

Thus, every repowering opportunity begins with one question:

Which Envelope Family does the existing turbine belong to?

3. The Intermediate — Five IACs and Three IBPs

Once the existing turbine has been classified, the repowering configuration is described through one of five standardized **Interface Architecture Classes (IACs)**.

The IACs define the permitted structural arrangements for connecting the nuclear heat source to the existing turbine. Each IAC is a complete architectural configuration; projects are not intended to assemble arbitrary combinations of elements from different IACs. IAC-IBP

Table 2 — Interface Architecture Classes and Interface Boundary Points

IAC	Interface Architecture	Basic Configuration	IBP	IBP Location
IAC-A	Direct Nuclear Steam	Nuclear steam supplied directly to turbine	IBP-1	Nuclear steam-generator outlet
IAC-B	Nuclear Steam + Electric Topping	Nuclear steam passes through electric supplemental heating before turbine admission	IBP-3	Immediately upstream of electric topping equipment
IAC-C	Nuclear Steam + Fired Topping	Nuclear steam passes through fired supplemental heating before turbine admission	IBP-3	Immediately upstream of fired topping equipment
IAC-D	Dual-Loop Hybrid	Nuclear heat transferred through an intermediate heat-transfer loop	IBP-2	Intermediate-loop heat-transfer interface
IAC-E	High-Temperature Indirect Cycle	Nuclear heat transferred through an intermediate loop into an indirect/advanced cycle	IBP-2	Intermediate-loop heat-transfer interface

This produces an important simplification:

Five IACs do not create five different types of nuclear/non-nuclear boundary. They collapse into three IBPs.

The relationship is:

IAC → IBP

IBP	IACs Using the IBP	Boundary Concept
IBP-1	IAC-A	Boundary at nuclear steam-generation outlet
IBP-2	IAC-D, IAC-E	Boundary at intermediate heat-transfer interface
IBP-3	IAC-B, IAC-C	Boundary immediately before supplemental heating

The IBP is therefore not an additional independent choice. It is part of the architectural definition of the IAC. The standard explicitly defines the dependency as **IAC → Integration Structure → IBP**. IAC-IBP

This gives the intermediate point of the framework a particularly clean structure:

Five architectural classes → three standardized physical boundary points.

4. End 2 — Heat Output Classes

The other end of the framework is the **Heat Output Class (HOC)**.

The HOCs provide a standardized classification of nuclear heat-output capability. They are deliberately expressed as classes rather than as individual reactor designs.

The purpose is therefore to establish a common vocabulary for describing the heat-output side of a repowering configuration.

NRIA defines four Heat Output Classes. IAC-IBP

Table 3 — Heat Output Classes

HOC	Description	Temperature Range	Defining Characteristic	Typical Application Context
HOC-A	Direct Thermal Match	≤500°C	Reactor must match turbine temperature and pressure directly, with no supplemental heat	Direct steam integration
HOC-B	High-Pressure Bulk Energy	300–450°C	High-pressure bulk energy with supplemental temperature addition	Electric or fired topping
HOC-C	Fluid-Driven Isolation	≥400°C primary temperature	Medium-temperature heat requiring full isolation loop	Intermediate-loop architectures
HOC-D	High-Temperature Isolation	>500°C for EF-3; >550°C for EF-4	High-temperature heat with advanced isolation and materials	High-temperature / USC applications

The HOC is therefore simply the **heat-output classification at the second end of the framework**.

It should not be interpreted here as a reactor-selection mechanism. The purpose of the classification is to provide a standardized label for the heat-output category associated with a permitted repowering configuration.

5. The Standardized Compatibility Matrix

The three elements can now be brought together.

The existing turbine is identified by its **EF**.

The integration arrangement is identified by its **IAC**, with the corresponding **IBP** automatically defined.

The heat-output category is identified by its **HOC**.

The resulting matrix shows the **allowable and non-allowable combinations**.

Table 4 — EF × HOC Compatibility Matrix

Envelope Family (EF)	HOC-A — Direct Match	HOC-B — Bulk Energy	HOC-C — Fluid-Driven Isolation	HOC-D — High-Temperature Isolation
EF1 — Subcritical (Low Grade)	IAC-A	PROHIBITED	IAC-D / IAC-E	PROHIBITED
EF2 — Subcritical (Standard Grade)	IAC-A	IAC-B / IAC-C	IAC-D / IAC-E	PROHIBITED
EF3 — Supercritical	PROHIBITED	IAC-B / IAC-C	PROHIBITED	IAC-D / IAC-E
EF4 — Ultra-Supercritical (USC)	PROHIBITED	PROHIBITED	PROHIBITED	IAC-D / IAC-E

This is the central standardization result.

The matrix does not attempt to design the plant. It simply answers:

Given an existing turbine classified as EF-X, which interface architectures are permitted, and which Heat Output Class is associated with each permitted combination?

The matrix consequently turns what would otherwise be a large number of individual turbine–nuclear combinations into a finite set of standardized categories.

6. Reading the Matrix

The matrix can be read in either direction.

Starting with the turbine

If the existing turbine is **EF-1**, the allowable configurations are:

- IAC-A $\rightarrow$ HOC-A
- IAC-D $\rightarrow$ HOC-C
- IAC-E $\rightarrow$ HOC-C

IAC-B and IAC-C are not permitted.

If the turbine is **EF-2**, the allowable configurations expand:

- IAC-A $\rightarrow$ HOC-A
- IAC-B $\rightarrow$ HOC-B
- IAC-C $\rightarrow$ HOC-B
- IAC-D $\rightarrow$ HOC-C
- IAC-E $\rightarrow$ HOC-C

For **EF-3**, the allowable configurations are:

- IAC-B $\rightarrow$ HOC-B
- IAC-C $\rightarrow$ HOC-B
- IAC-D $\rightarrow$ HOC-D
- IAC-E $\rightarrow$ HOC-D

For **EF-4**, the permitted configurations are limited to:

- IAC-D $\rightarrow$ HOC-D
- IAC-E $\rightarrow$ HOC-D

The significance is not that one configuration is necessarily preferable to another. Rather, the matrix establishes the **standardized solution space**.

7. The Three-Point Structure

The complete framework can therefore be represented very simply:

The table above is conceptual rather than a one-to-one mapping. The actual allowable relationships are defined by the compatibility matrix in Table 4.

The important point is that the framework has **three distinct classification points**:

1. Existing Asset — EF

What turbine are we repowering?

Four standardized Envelope Families classify the existing turbine's thermodynamic envelope.

2. Interface — IAC / IBP

What standardized architecture connects the nuclear system to that turbine?

Five IACs define the permitted architectures, while three IBPs define the corresponding nuclear/non-nuclear boundary locations.

3. Heat Output — HOC

What class of nuclear heat output is associated with the configuration?

Four HOCs provide the standardized heat-output categories.

Together:

EF + IAC/IBP + HOC = a standardized repowering configuration.

8. Why This Matters for Standardization

The value of the framework is its **finite structure**.

Instead of describing every repowering project through bespoke engineering terminology, the project can be described using a small number of standardized identifiers:

EF-1 / IAC-A / IBP-1 / HOC-A

or

EF-3 / IAC-C / IBP-3 / HOC-B

or

EF-4 / IAC-D / IBP-2 / HOC-D

Each identifier conveys a defined position within the standard.

The framework therefore creates a common classification language for the repowering industry without requiring every project to create its own architecture.

It also makes clear that the three points are **not independent variables**:

- The **EF** describes the existing turbine;
- The **IAC** describes the permitted integration architecture;
- The **IBP** follows from the IAC;

- The **HOC** is the heat-output class associated with the allowable EF–IAC combination.

The matrix is consequently the mechanism that connects the three points.

9. Conclusion

Standardization of nuclear repowering does not require every existing turbine, nuclear system or power island to be identical.

It requires the **interface between them to be classifiable**.

The NRIA framework achieves this by reducing the repowering landscape to three points:

END 1 — Envelope Family

Classification of the existing turbine

INTERMEDIATE — IAC + IBP

Classification of the permitted integration architecture and its nuclear/non-nuclear boundary

END 2 — Heat Output Class

Classification of the associated heat-output category.

The five IACs collapse into three IBPs, and the four EF categories and four HOC categories are connected through a finite compatibility matrix.

The result is a standardized map of **who can sit where and which combinations are permitted**.

That is the essential purpose of the framework:

Not to design every nuclear repowering project, but to define the finite set of configurations within which nuclear repowering can be standardized.

References:

1. Sinha, A. (2026). *The Triadic Law of Systems Reliability: Preventing Failure, Securing Lifecycle Continuity, and De-Risking Capital Allocation via the Three-Point Architecture Benchmark*. Novonanmek Material Sciences Private Limited. <https://novonanmek.com/>
2. Sinha, A. (2026). *The Triadic Law of Infrastructure Resilience: De-Risking Capital Allocation via the Three-Point Architecture Principle*. Novonanmek Material Sciences Private Limited. <https://novonanmek.com/>
3. Sinha, A. (2026). *The Three-Part Corridor Archetype: Cross-Domain Architectural Standardization in HOPT-AS and HLAS Clean Energy Infrastructure*. Novonanmek Material Sciences Private Limited. <https://novonanmek.com/>
4. Sinha, A. (2026). *Three-Point Architecture Principle: The Common Architectural Frame for HOPT-AS, HLAS, NRIA and NEIA*. Novonanmek Material Sciences Private Limited. <https://novonanmek.com/>