

Distinguishing Heavy Water Production and Upgrading Equipment from General Industrial Equipment under the Revised NSG Guidelines

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1. Introduction

Heavy water production and upgrading facilities are sensitive facilities used to produce and upgrade reactor-grade heavy water required for heavy-water reactors using natural uranium and are subject to control under the Nuclear Suppliers Group (NSG) Guidelines [1,2]. Such facilities have historically been established mainly in countries operating heavy-water reactors, including India, Canada, Romania, and Argentina. At present, publicly confirmed large-scale production of reactor-grade heavy water continues in India, while existing production facilities in Canada and Romania have been shut down or are no longer in operation, and Argentina is preparing to restart its heavy water production facility [3-6].

The previous NSG control framework for heavy water production facilities focused primarily on conventional large-scale production processes, such as the water-hydrogen sulfide exchange process (Girdler-Sulphide process, GS process) and the ammonia-hydrogen (A-H) exchange process. However, in the early 2000s, hydrogen-water isotope exchange technology using wet-proofed platinised catalysts was demonstrated to have the potential for industrial-scale application with favorable economics. This development highlighted the need to update the scope of control, leading to the revision of the NSG Guidelines in April 2026.

This study analyzes the revisions to the NSG Guidelines related to heavy water production and upgrading facilities and compares the technical characteristics of equipment and processes used in general industry with those used for heavy water production and upgrading. In addition, the implications of the revisions for domestic industries and the implementation of nuclear export and import controls are examined, and an approach for distinguishing heavy water production and upgrading equipment for nuclear applications from equipment used in general industrial applications is proposed.

2. Analysis and Results

2.1 Analysis of the Revised NSG Guidelines for Heavy Water Production and Upgrading

The NSG Guidelines consist of Part 1 and Part 2, which establish control frameworks for nuclear-specific

items listed on the Trigger List and nuclear-related dual-use items, respectively. Equipment and columns for heavy water production and upgrading are covered under Part 1, Section 6, while wet-proofed platinised catalysts themselves are included in Part 2, Section 2.A.2. In addition, heavy water and deuterium for use in nuclear reactors are specified as controlled items under Part 1, Section 2.1, whereas those not intended for reactor use are not covered by this section.

In the recently revised NSG Part 1 Rev.15, Section 6, three catalytic hydrogen-water isotope exchange processes—Combined Electrolysis and Catalytic Exchange (CECE), Combined Industrial Reforming and Catalytic Exchange (CIRCE), and Bithermal Hydrogen-Water Exchange (BHW)—were added alongside the conventional GS and ammonia-hydrogen exchange processes. The infrared absorption analyzer entry in Section 6.6, which had broad applicability in general industry, was deleted. Section 6.8 was revised to explicitly include complete heavy water finishing units and to specify a minimum diameter of 0.1 m for columns used in heavy water upgrade systems.

The conventional processes described in Section 6 of NSG Part 1 are based on large exchange towers and high-capacity circulation systems. The GS process uses highly corrosive and toxic hydrogen sulfide as the isotope-exchange medium, whereas the ammonia-hydrogen exchange process uses isotope exchange between liquid ammonia and hydrogen under high-pressure conditions exceeding 15 MPa.

In contrast, the newly added CECE, CIRCE, and BHW processes employ wet-proofed platinised catalysts for hydrogen-water isotope exchange and can operate under relatively moderate pressure conditions [7]. A common key component of these processes is a catalytic exchange column packed with wet-proofed platinised catalysts. CECE and CIRCE utilize hydrogen supplied from an electrolyzer and a steam reformer, respectively, whereas BHW enriches deuterium by exploiting the temperature-dependent difference in isotope equilibrium between hydrogen and water. Under Section 6.10 of the revised NSG Guidelines, hydrogen isotope exchange columns or towers are specified as being capable of operation at internal pressures of 0.1–4 MPa. This pressure range is substantially lower than the pressure specified for the ammonia-hydrogen exchange process. Although this pressure range partially overlaps with that of the GS process (~2 MPa), the use of hydrogen and water

instead of highly corrosive and toxic hydrogen sulfide provides comparatively less severe operating conditions.

Table I. Comparison of heavy water production processes

	GS	A-H	CECE	CIRCE	BHW
Isotope Exchange	H ₂ O(l)–H ₂ S(g)	NH ₃ (l)–H ₂ (g)	H ₂ O(l)–H ₂ (g)		
Gas-phase Medium	H ₂ S	H ₂ (Syngas)	H ₂ (EL ^a)	H ₂ (SR ^a)	H ₂ (loop)
Pressure (MPa)	2–2.2	>15	0.1–0.12 ^b	2–4 ^b	2.2 ^b
Catalyst	–	KNH ₂	Wet-proofed Pt		
Column Size ^c	XL	L	S–L	M–L	M–L

^a EL: electrolysis; SR: steam reforming

^b Representative operating pressures; actual operating pressures may vary depending on process design and integration [7].

^c Relative comparison of typical column sizes among the processes; actual dimensions may vary depending on plant capacity and design.

Along with the addition of new heavy water production and upgrading processes to Part 1, the control entry for wet-proofed platinised catalysts, which are key components of these processes, was also revised under Part 2, Section 2.A.2. Previously, the Guidelines controlled platinised catalysts used for heavy water production and for tritium recovery from heavy water through hydrogen-water isotope exchange. Under the revised Guidelines, the controlled catalyst was more specifically defined as a wet-proofed platinised catalyst, and heavy water upgrading was explicitly included as an intended application. In addition, the application for tritium recovery was expanded from heavy water to water, reflecting the broader applicability of hydrogen isotope exchange processes.

Accordingly, this study also confirmed the corresponding revision of Part 2 for wet-proofed platinised catalysts, together with the incorporation of the new processes into Part 1.

2.2 Criteria for Distinguishing Heavy Water Production and Upgrading Facilities

Columns, compressors, electrolyzers, steam reformers, and heat exchangers used in heavy water production and upgrading processes are also widely employed in the general chemical and refining industries, making it difficult to determine whether such equipment is intended for heavy water production or upgrading based solely on equipment names or external appearance. In addition, operating conditions such as pressure, temperature, size, and flow rate may substantially overlap with those of general industrial processes. Therefore, determining whether equipment constitutes part of a heavy water production or upgrading facility requires a comprehensive review of equipment configuration and operating characteristics rather than relying on a single technical specification.

The newly added processes employ gas-liquid counter-current isotope-exchange columns

characterized by relatively large height-to-diameter ratios and packed with wet-proofed platinised catalysts. Hydrogen and water are brought into repeated contact within the exchange system, and multiple exchange columns or stages may be arranged to achieve repeated isotope exchange and enrichment. CECE is integrated with an electrolyzer, CIRCE with a steam reformer, and BHW consists of exchange columns operated at different temperatures together with a hydrogen circulation system. These process configurations can serve as supplementary technical indicators for distinguishing equipment used in heavy water production and upgrading facilities from general chemical and refining equipment.

However, the operating conditions and process characteristics of the newly added processes may overlap with those of general chemical and refining processes depending on the design, and therefore cannot alone provide a sufficient basis for identifying heavy water production and upgrading facilities. Accordingly, this study categorized the relevant technical characteristics into those directly specified in the NSG Guidelines and supplementary technical indicators derived from the configuration and operating characteristics of the new processes, as summarized in Table II. The hydrogen isotope exchange function, wet-proofed platinised catalyst configuration, materials of construction, and operating capabilities specified in the NSG Guidelines were considered collectively as the primary technical characteristics, followed by additional examination of process integration, staged enrichment configuration, the role of hydrogen, gas-liquid contact mode, and equipment configuration. These supplementary technical indicators are not intended to independently determine the control status of an item, but rather to provide technical information for identifying whether the equipment constitutes part of a heavy water production or upgrading facility when considered together with the applicable NSG control specifications.

Table II. Technical characteristics and supplementary technical indicators for distinguishing heavy water production/upgrading equipment from general chemical/refining equipment

Feature	General Chemical/Refining	New Heavy Water Production/Upgrading
Function	Designed for reaction, absorption, separation, etc.	column/tower especially designed or prepared for hydrogen isotope exchange ¹
Catalyst type/configuration	Ni, Co-Mo/Ni-Mo, Pt/Pd; fixed-, moving-, or slurry-bed etc.	Packed with random or structured wet-proofed Pt ¹
Material	Carbon steel, stainless steel, alloy steel, etc.	Carbon steel or stainless steel ¹
Operating capability	Vacuum/high pressure; ambient/high temperature	0.1–4 MPa; 20 – 200 °C ¹
Process integration	Integrated with feed, reaction, separation, and heat-transfer systems	Functionally integrated with an electrolyzer (CECE), a steam reformer (CIRCE), or an H ₂ circulation system (BHW) ²

Feature	General Chemical/Refining	New Heavy Water Production/Upgrading
Process configuration	Single or multiple reaction/separation stages	Repeated isotope exchange and staged enrichment ²
H ₂ role	Reactant or process/recycle gas	Hydrogen isotope exchange medium ²
Contact mode	Co-current/counter-current, cross-flow, mixed contact, etc.	Counter-current H ₂ (g)-H ₂ O(l) contact ²
Equipment configuration	Absorption/distillation columns, packed columns, fixed-bed reactors, etc.	Tall vertical (large height-to-diameter ratio) isotope-exchange column/tower ²

¹ Technical characteristics directly specified in the NSG Guidelines. The listed characteristics correspond to the combined specifications of NSG Part 1, Section 6.10 and should be considered collectively; they do not constitute independent control criteria.

² Supplementary technical indicators proposed in this study for distinguishing heavy water production or upgrading equipment from general industrial equipment.

The technical indicators presented in Table II can be reviewed in relation to the relevant NSG control entries. The function, catalyst type and configuration, materials of construction, and operating capabilities are directly related to the control specifications for hydrogen isotope exchange columns or towers under Part 1, Section 6.10, while wet-proofed platinized catalysts themselves are also covered under Part 2, Section 2.A.2 [1,2]. In contrast, process integration, staged enrichment configuration, the role of hydrogen, gas-liquid contact mode, and equipment configuration are supplementary technical indicators derived in this study based on the process and operating characteristics of CECE, CIRCE, and BHW. Accordingly, the former can be used as primary technical characteristics for assessing conformity with the applicable control specifications, whereas the latter can provide supplementary information for further assessing the heavy water production or upgrading function of the equipment.

CECE, CIRCE, and BHW share the common characteristics of H₂–H₂O isotope exchange using wet-proofed platinized catalysts, but differ in their hydrogen supply methods and system configurations. Therefore, the common NSG control specifications should first be reviewed, followed by process-specific supplementary technical indicators reflecting the distinctive characteristics of each process. The major process-specific supplementary technical indicators are summarized in Table III.

Table III. Process-specific supplementary technical indicators for CECE, CIRCE, and BHW

Process	Supplementary technical indicators
CECE	Catalytic exchange column–electrolyzer integration, electrolytic H ₂ supply, staged isotope exchange and enrichment
CIRCE	Catalytic exchange column–steam-hydrocarbon reformer integration, reformer H ₂ supply
BHW	Cold/hot catalytic exchange towers, H ₂ circulation system, temperature-dependent isotope enrichment

2.3 Domestic Implications

In the Republic of Korea (ROK), heavy water and deuterium are used in non-nuclear applications, including OLED displays, semiconductors, and pharmaceuticals, and industrial demand for heavy water production and upgrading is increasing. Recently, IT-CHEM Co., Ltd. established a heavy water production facility with an annual capacity of approximately 10 tons at its Goesan Plant 1 in Chungcheongbuk-do. The company has also developed technology for recycling spent heavy water [8]. The produced heavy water is intended for non-nuclear industrial applications, including display and semiconductor manufacturing [8], and the company is also developing catalyst-based heavy water production and upgrading technologies, including a registered patent for a CECE-based apparatus for the separation and concentration of heavy water [9]. As such industrial applications expand, non-nuclear companies, in addition to conventional nuclear operators, are expected to increasingly develop and introduce equipment and technologies related to heavy water production and upgrading.

When technologies, equipment, and facilities related to heavy water production and upgrading are imported from abroad, they may be subject to control under the NSG Guidelines depending on whether they meet the applicable control specifications, and may also fall within the scope of an applicable bilateral Nuclear Cooperation Agreement (NCA). Accordingly, when requested by the exporting country, the government of the importing country reviews the purpose of the import and the qualification of the importer and issues a Government-to-Government Assurance (GTGA) or provides an Acknowledgement of Receipt (AOR) to the exporting country in accordance with the applicable procedures. The importer may also be required to prepare and submit an End-User Statement. Following import, the importer may be required to maintain an inventory, comply with annual inventory reporting requirements in accordance with the applicable NCA and the terms of the GTGA provided at the time of import.

In particular, when equipment or technology transferred from Canada is subject to the ROK–Canada NCA, items produced or developed using such equipment or technology may also fall within the scope of the NCA, depending on the applicable definitions and transfer conditions, and may therefore be subject to inventory maintenance and annual inventory reporting requirements [10]. In addition, when the imported technology or equipment is retransferred to a third country, prior consent from or notification to the supplier country may be required, depending on the applicable NCA and the terms of the GTGA or AOR provided by the government and the End-User Statement submitted by the importer. Therefore, as the development and introduction of heavy water production and upgrading facilities expand into non-nuclear sectors, non-nuclear industrial companies as

well as conventional nuclear operators may become responsible for complying with import-related regulatory requirements at the time of import, maintaining required inventories, and meeting prior-consent or notification requirements for retransfers.

3. Discussion

The newly added processes in the NSG Guidelines have essentially the same technical characteristics regardless of whether the equipment is intended for nuclear or non-nuclear applications. Accordingly, equipment used in non-nuclear industries may also meet the NSG control specifications. Therefore, technical indicators are needed to assess the function and production or upgrading capability of such equipment so that effective control of nuclear-related heavy water production and upgrading facilities can be maintained without imposing unnecessary regulatory burdens on industry. Although this study proposed several supplementary technical indicators for identifying heavy water production and upgrading equipment, the D₂O concentration of the feed and the processing capacity should also be considered when assessing the production or upgrading capability of such equipment.

When the D₂O concentration of the feed is relatively low, larger processing capacities and multiple enrichment stages may be required to achieve the target concentration, making equipment scale and process configuration important considerations. According to the NSG Guidelines, the first large enrichment stage of a CECE process typically increases the deuterium concentration by a factor of approximately 5-20, and the largest hydrogen production plants in the world produce sufficient hydrogen to extract approximately 20-60 Mg of heavy water per year using a CECE or CIRCE process [1]. Therefore, for these processes, the processing capacity and degree of integration with the associated hydrogen production system should be considered together. In contrast, BHW can be configured based on an independent hydrogen circulation system; therefore, its process-specific characteristics should be considered rather than applying the same technical indicators used for CECE and CIRCE.

When the D₂O concentration of the feed is relatively high, fewer enrichment stages and a lower processing throughput are required to reach the target concentration, allowing upgrading to high-purity heavy water even with relatively small-scale equipment. Such equipment may be used as part of a heavy water upgrade system to supply heavy water or deuterium to non-nuclear industries, while it may also be used in connection with heavy-water reactors to maintain or restore the required heavy water concentration, or as a final upgrading stage of a heavy water production process. Therefore, in such cases, in addition to the technical identification of the equipment, its connection to a nuclear reactor or heavy water production facility and its intended end-use should be further reviewed.

4. Conclusion

This study analyzed the revisions to NSG Part 1 Rev.15 related to heavy water production and upgrading facilities and examined supplementary technical indicators for distinguishing heavy water production and upgrading equipment from equipment used in general chemical and refining industries. Although the revised Guidelines explicitly incorporated catalyst-based processes such as CECE, CIRCE, and BHW, as well as heavy water upgrade systems, components such as columns, electrolyzers, and steam reformers are also widely used in general industry, and their operating pressure, temperature, and equipment configuration may substantially overlap. Therefore, heavy water production and upgrading equipment cannot be reliably distinguished based solely on equipment names, external appearance, or a single operating specification.

Accordingly, the technical characteristics directly specified in the NSG Guidelines, including columns or towers especially designed or prepared for hydrogen isotope exchange, wet-proofed platinised catalyst configuration, materials of construction, and operating capabilities, should serve as the primary basis for technical identification. This study proposed supplementary technical indicators, including process integration, repeated isotope exchange and staged enrichment configuration, the role of hydrogen, and H₂–H₂O gas-liquid contact mode, to be considered together with the NSG control specifications. Separately from this technical identification, the connection of the equipment to a nuclear reactor or heavy water production facility and its intended end-use should also be reviewed.

In the ROK, the use of heavy water and deuterium is expanding in non-nuclear sectors such as displays and semiconductors, and the development and introduction of heavy water production and upgrading equipment and related technologies are also increasing. Accordingly, not only nuclear operators but also relevant non-nuclear industrial companies may become responsible for implementing nuclear export and import control requirements. When related equipment and technologies are imported from abroad, requirements related to import procedures, inventory maintenance and annual inventory reporting, and prior consent or notification for retransfers may apply under the applicable NCA, in addition to determining the control status of the items.

Meanwhile, this study did not derive quantitative relationships among feed D₂O concentration, processing capacity, equipment scale, and heavy water production or upgrading capability. Future work should therefore analyze the enrichment performance and processing capacity of CECE, CIRCE, and BHW and quantify the relationships among feed concentration, equipment scale, and process configuration. Based on such analysis, more detailed technical indicators and criteria for distinguishing general industrial equipment from

heavy water production and upgrading equipment should be developed. Such a framework is expected to improve the objectivity and effectiveness of controls on nuclear-related heavy water production and upgrading facilities while minimizing unnecessary regulatory impacts on non-nuclear industries.

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