Designing a Nuclear Reactor Pressure Vessel: Codes, Regulations, and Off-the-Shelf Options

1. Applicable Codes and Regulations for a Reactor Pressure Vessel (RPV)

ASME Boiler & Pressure Vessel Code (BPVC) Section III: In the United States, any reactor coolant pressure boundary component (including the RPV of a PWR) must be designed and constructed to **ASME BPVC Section III, Division 1, Class 1** standards. Section III provides the rules for materials, design, fabrication, examination, and testing of nuclear-grade components. For an RPV, the relevant subsections are typically Subsection **NB** (Class 1 components) along with referenced portions of Section II (material specifications), Section V (nondestructive examination), and Section IX (welding qualifications). In practice, this means the RPV must be built by an ASME-certified manufacturer (holding an "N-Stamp") under a strict quality program, using approved materials (e.g. SA-508 low-alloy steel forgings) and meeting specific stress limits and design margins. Section III Class 1 imposes conservative stress limits for normal/upset conditions (Service Levels A/B) and requires analysis of emergency and faulted conditions (Levels C/D) with defined safety factors. For example, primary membrane stress must remain below 2/3 of the material yield strength under normal operation, and the vessel must withstand transient pressures (such as LOCA or seismic events) without plastic instability. The code also requires fatigue analysis of cyclic loads and provides **over-pressure protection** criteria (typically requiring a relief capacity such that pressure does not exceed 110% of design). Overall, compliance with Section III ensures a large safety margin and high reliability in the RPV design.

10 CFR 50.55a – Incorporation of Codes: NRC regulations explicitly mandate the use of ASME Section III for nuclear power plant components. **10 CFR 50.55a(c)(1)** requires that the reactor coolant pressure boundary components meet **ASME Section III Class 1** requirements. This ties the federal regulation to the ASME Code, including any NRC-specified addenda or conditions. (For instance, the NRC may stipulate use of a particular ASME edition and may impose additional conditions – such as augmented examinations or quality assurance – via 10 CFR 50.55a or Regulatory Guides.)

General Design Criteria (GDC) – Reactor Coolant Pressure Boundary: Appendix A to 10 CFR 50 contains the General Design Criteria, several of which apply directly to the RPV. **GDC 14 ("Reactor coolant pressure boundary")** requires the RPV and connected pressure boundary to be designed, fabricated, and tested so as to have **"an extremely low probability of abnormal leakage, of rapidly propagating failure, and of gross rupture."** In short, the vessel must be ultra-reliable. **GDC 30 ("Quality of reactor coolant pressure boundary")** and **GDC 1 ("Quality standards and records")** further enforce that recognized codes and high-quality standards (like ASME BPVC and ANSI standards) be used, and that a quality assurance program (Appendix B to Part 50) is in place for design, fabrication, and documentation.

Fracture Toughness and Material Embrittlement: GDC 31 ("Fracture prevention of RCPB") mandates that the RPV be designed with **sufficient margin** to behave in a non-brittle manner under all conditions (including startup/cooldown and postulated accidents) and to **minimize the probability of rapidly propagating fracture**. This criterion recognizes that the RPV material (ferritic steel) becomes less tough at low temperatures and that neutron irradiation in service can cause embrittlement. To implement GDC 31, the NRC has **10 CFR 50 Appendix G, "Fracture Toughness Requirements,"** which sets specific rules. Appendix G requires that **ferritic materials in the RPV have adequate fracture toughness margins** under all operating and testing conditions. In practice, this leads to requirements for **pressure-temperature (P-T) limit curves** for heatup and cooldown operations, ensuring the RPV is not operated at low temperature and high pressure concurrently. It also imposes minimum toughness criteria (e.g. reference nil-ductility transition temperature, RT_{NDT}, and Charpy V-notch energy requirements) for the RPV steel and welds. The ASME Code (Section III and Section XI) is referenced for the methods to calculate stress intensity factors and allowable fracture toughness; for example, Appendix G to Section XI provides the methodology to establish P-T limits that satisfy the safety margins required by 10 CFR 50 App G. Simply put, the vessel must be operated in a temperature-pressure regime that precludes brittle fracture – typically requiring the reactor coolant to be heated above a minimum temperature before pressure is raised.

In addition, **10 CFR 50 Appendix H, "Reactor Vessel Material Surveillance Program,"** is applicable since we have an NRC-licensed plant. Appendix H requires that reactor vessel material specimens (coupons from the same material and welds as the RPV) be installed inside the vessel and periodically removed for testing. This surveillance program monitors the **embrittlement trend (shift in transition temperature and drop in toughness)** as the vessel accrues neutron fluence over years. The surveillance data must be used to **update P-T limits** and ensure continued compliance with fracture toughness criteria. GDC 32 ("Inspection of RCPB") ties in here, requiring the RPV design to **permit periodic inspection and an appropriate material surveillance program**. Practically, the RPV is built with **coupons in surveillance capsules** and with design features to allow nondestructive examination of critical areas (for example, the vessel includes openings or flange designs that permit ultrasonic inspection of welds during outages).

Inspection and Testing Requirements: Besides the initial construction code, NRC regulations enforce **in-service inspection (ISI)** and testing throughout the life of the RPV. Per 10 CFR 50.55a(g), the plant's ISI program must use **ASME Section XI** for periodic inspection of Class 1 components. Section XI requires volumetric examinations (typically ultrasonic) of RPV welds and shell regions on a 10-year interval, leak testing each refueling cycle, and other examinations to detect any flaws or aging effects. This affects the design because the RPV must include provisions (such as accessible weld geometry or built-in nozzles for inspection scanners) to facilitate these inspections. Furthermore, the **hydrostatic pressure test** (at or above operating pressure) that the RPV undergoes before operation and periodically (per Section XI) verifies its leak-tightness. All of these code and regulatory requirements ensure that the RPV is not only robustly designed and built, but also monitored and maintained so as to **preclude failure through the plant's life**.

Other Relevant Regulations and Guides: Because the RPV is safety-critical, **10 CFR 50 Appendix B (Quality Assurance)** applies to its procurement, fabrication, and installation. This means the manufacturer must have a QA program meeting Appendix B and typically ASME NQA-1. Also, **10 CFR Part 21 (Reporting of defects)** applies – if any potential defect or noncompliance in the RPV or its materials is discovered, it must be evaluated and reported. The NRC has issued Regulatory Guides such as **RG 1.26** (Quality Group classifications) which classifies the RPV as Quality Group A, corresponding to ASME Class 1. **Regulatory Guide 1.50** and **1.99** deal with reactor vessel material toughness and embrittlement monitoring (for example RG 1.99 provides methods to predict the irradiation embrittlement of RPV steels, used in setting pressure-temperature limits). General Design Criterion 30 also implies the RPV design include means to detect and control leakage – in practice RPVs are built with leak monitoring (e.g. flange leak-off lines) to ensure any through-wall leak would be detected well before gross failure.

Summary of Constraints: In summary, the applicable codes and regulations impose strict **constraints on materials** (must be nuclear-grade and traceable), **design margins** (safety factors on stress and fracture toughness), **fabrication processes** (qualified welding procedures and inspections), and **quality assurance** (documentation and testing at every step). For the reactor designer, this means the RPV must be designed according to ASME Section III rules (performing a detailed stress analysis, fatigue evaluation, etc.), and the design must be reviewed against NRC criteria for pressure boundary integrity (GDC 14, 31) and inspectability (GDC 32). During procurement, only certain suppliers in the world can satisfy these requirements, and the RPV will go through rigorous shop inspections (e.g. radiography of welds, hydrotest at 1.25×design pressure, etc.). All these measures, while adding cost, are in place to ensure the RPV operates with an extremely low likelihood of failure over the plant's 40–60 year life.

2. Off-the-Shelf Pressure Vessel Options for an SMR PWR

Given the high cost and long lead time of a custom-forged RPV, we have investigated commercially available pressure vessels that might be procured “off-the-shelf” or with minimal custom engineering, for a **small modular PWR** (pressurized water reactor) with operating conditions of ~270 °C and pressure in the 3–15 MPa range. Below we list several categories of options, including their applicable code classification, pressure-temperature ratings, potential suppliers, and estimated costs:

A. Nuclear-Grade Reactor Vessels from Established Suppliers

One option is to procure an RPV from the **existing nuclear supply chain** – essentially the same type of vessel used in commercial reactors, but scaled to SMR size. These are built to **ASME Section III, Class 1** requirements (or equivalent foreign codes) and come from specialized heavy manufacturing firms. The **supplier base is limited** (only a handful of facilities globally can fabricate large nuclear RPVs), but for an SMR the size is somewhat smaller, which increases the pool of potential suppliers. Notable suppliers and their capabilities include:

- **Doosan Enerbility (South Korea):** Doosan is a major nuclear component manufacturer that has supplied **34 reactor vessels worldwide** (and 124 steam generators) for conventional reactors. They have forging presses (13,000 ton and 17,000 ton capacity) able to forge large ring shells and heads. Doosan has partnered with NuScale Power to produce the RPVs for NuScale’s 77 MWe SMR design, and began forging material for those in 2023. For our SMR (15 MPa, 270 °C conditions, which are similar to large PWRs), a Doosan-fabricated vessel would use low-alloy steel forgings (typically SA-508 Gr.3 Cl.1) and be furnished with an ASME **N-Stamp**. **Estimated cost:** on the order of tens of millions of USD. Recent contract data suggests the cost: GE Hitachi’s BWRX-300 (300 MWe SMR) RPV contract to BWXT plus some other components is part of a CAD 1 billion package, and the RPV portion alone is likely on the order of **$30–50 million**. Similarly, industry experts have cited approximately **$150 million for a large single-forged RPV** of a ~1100 MWe plant. An SMR vessel, being smaller, would cost less – perhaps in the few tens of millions range – but still significantly higher than a comparable industrial vessel due to nuclear QA and certification overhead.
- **BWX Technologies (BWXT, Canada/US):** BWXT’s Canadian division (formerly Babcock & Wilcox Canada) is now building the **RPV for GE Hitachi’s BWRX-300 SMR** under contract. BWXT has a manufacturing facility in Ontario capable of heavy nuclear fabrication and is expanding to support multiple SMR projects. BWXT could be a supplier for a PWR-type SMR vessel as well. They have experience with CANDU reactor components and naval reactor components. Applicable code would be ASME Section III; BWXT holds ASME N-Stamp certifications. **Pressure-temperature rating:** The BWRX-300 vessel (being a boiling water reactor) is designed for ~7 MPa, 285 °C (saturated), but the manufacturing techniques apply equally to a 15 MPa, 270 °C PWR

vessel. **Estimated cost:** likely similar to Doosan's. The Canadian contract for BWRX-300 RPV plus other work was part of >CAD 1 billion in awards (the RPV itself likely a few tens of millions CAD).

- **Japan Steel Works (JSW, Japan):** JSW is renowned for its large forgings – it supplied ~80% of world nuclear RPV forgings at one point. JSW has **manufactured ~130 reactor pressure vessels in service worldwide** world-nuclear.org. They can forge large one-piece shells (up to ~600 ton ingots), which was historically mandated to minimize welds. JSW could supply forged shells and heads for an SMR vessel. They adhere to ASME Section III and have supplied U.S. and European projects (JSW was the forge for many European EPR and US AP1000 RPVs) world-nuclear.orgworld-nuclear.org. **Estimated cost:** similar high tens of millions. (JSW's large EPR vessel forgings and fabrication might exceed $100 M, but an SMR would be less.) However, ordering from JSW would involve overseas transport and doesn't truly save cost unless their forging capability allows a simpler design (e.g. fewer welds).
- **Framatome / Le Creusot (France):** Framatome's Le Creusot forge (recently modernized) fabricated the RPVs for the EPR reactors (Hinkley Point C, for example, has a 500 ton RPV made by Creusot). While France is focused on large plants, a smaller RPV could potentially be sourced.
- **China's Manufactures (Shanghai Electric, China First Heavy Industries, etc.):** China has multiple heavy forging plants capable of ~5–8 RPV sets per year. They have made AP1000 and Hualong-1 vessels. In principle, Chinese companies could offer lower-cost manufacturing of an RPV. **Pressure ratings:** Chinese PWRs operate ~15 MPa, so their designs match our needs. **Applicable code:** They would conform to RCC-M (French code) or ASME, and many Chinese forged components have attained ASME certification. **Estimated cost:** potentially lower unit cost due to economies of scale in China; however, using a Chinese off-the-shelf vessel for a US-licensed reactor would introduce challenges in oversight, and the NRC would scrutinize the QA. Still, this is an option if cost is paramount (some Western SMR developers have explored partnerships in China to fabricate modules).

Pros/Cons: Buying a nuclear-grade vessel from these suppliers ensures full code compliance and regulatory acceptance, but **costs are very high** and lead times long (an RPV is typically a **long-lead item**, often requiring order 2–3 years before reactor installation). The manufacturing involves large forgings or multi-segment welds with extensive testing. The **constraints defined by Section III and NRC** (for example, a preference for single-piece forgings in the beltline to avoid weld embrittlement) are already incorporated in these suppliers' designs. To use these off-the-shelf, we might look at existing SMR designs' vessels – e.g. the **NuScale SMR vessel** (approx. 3.0 m in diameter, 25 m tall including integrated steam generator) being built by Doosan, or the GEH BWRX-300 vessel by BWXT – as reference points. Those designs meet our P-T requirements (NuScale's PWR module operates around 12–13 MPa and ~300 °C), so adapting one could save design effort. However, they are **not mass-produced yet**; each first-of-a-kind RPV is essentially custom and the price reflects that.

B. Industrial High-Pressure Vessels (ASME Section VIII)

Another approach to cost reduction is to consider **commercial industrial pressure vessels** that are **"off-the-shelf" in non-nuclear industries.** Many industrial processes use high-pressure vessels at comparable pressures and temperatures – for example, petrochemical reactors (ammonia synthesis converters operate in the 15–25 MPa range, albeit at higher temperature ~450 °C) or high-pressure test autoclaves. These vessels are built to **ASME Section VIII** (Division 1 or Division 2) standards, which are the general pressure vessel codes for non-nuclear service. While Section VIII vessels would not automatically meet all nuclear-specific criteria (and using them in a reactor would require a code deviation or equivalency argument to the NRC), they could be significantly **cheaper and quicker to procure**. We identified several categories and suppliers in this realm:

- **High-Pressure Autoclaves and Chemical Reactor Vessels:** Companies like **Melco Steel, Inc. (USA)** fabricate custom autoclaves and reactors for industry. Melco advertises capability to build autoclave vessels up to **3,000 psi (20.7 MPa) operating pressure and 1,500 °F (816 °C)**, with diameters up to **32 ft (9.8 m) and wall thickness 8 in (20 cm).** This indicates that **very large, thick-walled vessels** can be made by such suppliers under Section VIII. Our RPV needs (~15 MPa, 270 °C) fall well within these pressure/temperature bounds. **Applicable code:** likely ASME Section VIII Division 2 (which allows higher stress intensity for a given material – useful for thick, high-pressure designs – and includes fatigue analysis similar to Section III). **Supplier examples:** Melco Steel, or **Tank Fab, Inc.**, which builds autoclaves up to 160 ft long (though at lower pressures in some cases), or **High Pressure Equipment Co. (HiP)** which offers standard high-pressure vessels for lab/pilot use rated to 10,000 psi (68.9 MPa) in smaller sizes. **Estimated cost:** highly variable by size, but generally **far lower per ton of steel** than a nuclear vessel. For instance, a small ASME-certified autoclave (for composites curing, ~1 m diameter, but low pressure ~1 MPa) might only cost ~$15,000. A large thick-wall chemical reactor of several meters diameter at 15 MPa might cost in the low millions (e.g. an ammonia reactor vessel, which could be roughly comparable in size to an SMR core vessel, is on the order of a couple million USD). Even after adding some extra NDE and quality control, the cost is expected to be **10× or more lower than a Section III vessel**, because Section VIII fabrication has lower overhead and a larger competitive market.
  - **Design considerations:** An industrial vessel would still use high-grade materials (e.g. SA-533/SA-537 or Cr-Mo steels for high-pressure service). The main differences: allowable stress in Section VIII may be a bit higher (lower safety

factor on tensile strength than Section III's 3.0), and the quality program, while ASME stamped, is not the full NQA-1 nuclear program. That said, these vessels can be very robust – e.g. a typical Section VIII Division 2 design might have a factor of safety of ~2.4 on ultimate strength and incorporate fatigue design for the specified cycles, which could be acceptable for a reactor if properly justified. We would likely need to perform an **equivalency analysis** to show that using such a vessel does not compromise safety, or seek an NRC exemption/relief.

- **Examples of standard products: GENERON (USA)** provides ASME U-stamped pressure vessels for gas processing, with standard designs up to **16 ft (4.9 m) diameter, 100 ft (30 m) long, 4 in (10 cm) thick, and 60 ton weight**. These dimensions approach those of a small reactor vessel. Another example, **FIBA Technologies** offers ASME vessels for industrial gas storage up to 15,000 psi (though at smaller diameters ~24 in). **Holloway America** advertises stainless steel ASME vessels up to 12 ft diameter. Many such fabricators exist (in the US and globally), which means **competitive pricing**.
- **Estimated cost detail:** As a rough scale, consider a pressure vessel ~3 m ID, 6–8 m tall, designed for 15 MPa. If built to Section VIII Div 1 with, say, 150 mm wall thickness, the steel and fabrication might weigh on the order of 50–100 tons. At industrial fabrication rates (perhaps $10–20 per kg fully fabricated), the vessel could cost on the order of **$1–2 million**. Additional testing (full radiography, extra quality documentation) might add some cost, but we'd still be likely well under $5 million. This is an order of magnitude less than a nuclear-grade vessel.
- **Important constraints:** If we pursue this route, we must ensure that the vessel's **material and toughness** meet 10 CFR 50 App G requirements. Many industrial vessels use similar steels (SA-533/SA-537 are actually the same class used in nuclear), and these can be purchased with fine grain size and Charpy V-notch tests to meet nuclear toughness criteria. We'd also need to implement a **surveillance program** if the steel isn't already nuclear-certified – but we could likely incorporate surveillance coupons as with a normal RPV. The **biggest hurdle is regulatory:** we would need the NRC to agree that a Section VIII vessel, with perhaps a slightly different safety factor, still provides "equivalent protection." Notably, **GDC 1** allows use of "generally recognized codes and standards" if adequately justifiednrc.gov. Section VIII is an ASME recognized standard for pressure integrity (indeed used in non-safety systems of plants), so an argument could be made for cases where full Section III is overly conservative for a small design. We would also adopt a stringent QA approach (perhaps require the fabricator to implement an Appendix B-like program for this item).

C. Modular or Multiple-Vessel Concepts

We also considered if multiple smaller off-the-shelf vessels could be used in lieu of one large RPV. This is somewhat unconventional for a reactor (since a PWR typically needs a single pressure vessel around the core), but some advanced concepts use **distributed pressure boundaries**. For example, Canada's CANDU reactors use many small pressure tubes instead of one big vessel. In our context (an SMR PWR core), one idea could be to house **clusters of fuel in separate pressure vessels** (like "six-pack" of modules). Each module could be an **off-the-shelf high-pressure pipe or cylinder** (for instance, a standard high-pressure pipe vessel rated to 15 MPa). Standard high-pressure **gas cylinders** (for industrial gases) often have working pressures in the 15–20 MPa range, but their volumes are small (e.g. 40 L cylinders at 15 MPa are commercially available). We would need larger volumes (a core needs a few cubic meters of coolant). There are **standard pressure vessel sections** available (e.g. pipeline surge vessels, high-pressure separators) which could be repurposed.

While this approach might not suit a conventional PWR design, it could be relevant if we explore a novel reactor configuration (for example, a primary loop divided among multiple small vessels). The benefit would be using **commodity pressure vessels** that are mass-produced, thus cheap. However, we would incur complexity in reactor design and potentially multiple penetrations and core divisions.

Given the question focus, a more practical modular strategy is to use an **existing SMR RPV design** that is already developed, and see if we can procure it or its sections off-the-shelf. For instance, **Holtec's SMR-160** is a 160 MWe PWR – if Holtec or its suppliers have spare forging or a standard design, we might leverage that. Similarly, **Rolls-Royce SMR (UK)** plans a ~470 MWt PWR; they have been standardizing their vessel design (though not yet built). These are "off-the-shelf" in the sense of design availability, but not physically in inventory. Still, aligning with one of these programs could let us buy a vessel from the same vendor, potentially reducing our engineering costs.

D. Innovative Manufacturing for Cost Reduction (Future Outlook)

It's worth noting emerging methods that could drastically cut RPV cost. One cutting-edge approach is to **manufacture the vessel in smaller pieces and weld them together**, rather than a single massive forging. Historically, the NRC favored one-piece forgings for the beltline to avoid welds that could become brittle. But modern welding techniques – **especially electron-beam welding (EBW)** – and advanced materials processes – like **Powder Metallurgy + Hot Isostatic Pressing (PM-HIP)** – are being developed to produce RPVs more cheaply. Research led by EPRI and universities (e.g. Purdue) has shown that an RPV made in sections via PM-HIP and EBW could **reduce the cost by a factor of 100** (e.g. from \$150 M to about \$1.5 M). The idea is that **PM-HIP** can form near-net shape vessel sections with excellent properties, and EBW can join them with narrow, high-quality welds that are virtually indistinguishable (after proper heat treatment) from base metal. This could enable domestic fabrication in smaller facilities, avoiding the giant forgings that only a few international companies can do.

While this is **not yet a commercial "off-the-shelf" option**, it is on the horizon. Codes and standards are catching up – the ASME Code is considering code cases to allow PM-HIP and advanced welds for nuclear components, and the NRC would need to approve these on a case-by-case basis (material surveillance and testing are ongoing to qualify these processes). If our project timeline is long enough, this could become a viable path to **drastically lower the RPV cost** while still meeting all nuclear requirements. Essentially, it would transform RPV fabrication into a more modular, almost off-the-shelf process (with sections produced in batch and welded).

Summary of Options: In conclusion, to design our reactor vessel more cheaply, we should weigh these options. **Option A (traditional nuclear suppliers)** offers proven compliance and lowest licensing risk, but at very high cost. **Option B (industrial vessels)** offers huge cost savings and quicker availability, but would require overcoming regulatory hurdles and possibly making design compromises (or additional safety analysis to justify their use under a 10 CFR 50.55a alternative request). A hybrid approach might be to use an **industrial vessel with enhanced QA** as a **prototype or test unit** (where full NRC licensing might not be initially required, e.g. for a research or demonstration reactor under DOE), and then move to a Section III vessel for the fully licensed plant – lessons from the prototype could inform if a cheaper vessel performs adequately. Finally, keeping an eye on **innovations** in manufacturing could allow us to propose to the NRC a vessel that is both *cheaper* and *compliant*, if we become an early adopter of those techniques.

Each option's feasibility also depends on scale: our SMR (being PWR type around 270 °C, 15 MPa) is roughly in the same conditions as existing PWRs but at a smaller size. **Smaller size is key to cost savings** – for example, smaller diameter means the wall thickness (for a given pressure) can be less, and the forging or fabrication is easier. It also means some **off-the-shelf components (like high-pressure closures, flanges, nozzles)** can be procured from catalogs (since e.g. a standard 8-inch Class 2500 nozzle flange is rated to ~42 MPa at room temp, ~15 MPa at 343 °C, per ASME B16.5, which matches our needs). We could exploit these standard pipe fittings for things like vessel nozzles and manways instead of custom designing them – further reducing cost.

In table form below, we summarize a few representative vessel options identified:

- **Nuclear Forge RPV (Section III):** e.g. *Doosan-forged SMR Vessel.* **Rating:** 15 MPa @ 270–300 °C. **Code:** ASME Section III Class 1. **Supplier:** Doosan (S. Korea) or BWXT (Canada) among others. **Est. Cost:** $30–50 M (for ~SMR size). **Notes:** Fully compliant, long lead (2–3 yr), highest quality (N-stamp).

- **Industrial High-Pressure Vessel (Section VIII):** e.g. *Melco Steel Autoclave.* **Rating:** 20 MPa @ 815 °C (demonstrated capability) – more than sufficient for 15 MPa @ 270 °C. **Code:** ASME Section VIII Div. 2 (with "U" stamp). **Supplier:** Melco Steel (USA) or Generon, etc. **Est. Cost:** $1–5 M (depending on size). **Notes:** Much quicker fabrication (months), would need NRC exemption to use in a licensed plant; could serve as an interim or test option. Can be built in segments (cylinder + hemispherical heads) with standard flanges. Supplier Melco advertises up to 32 ft diameter, 8 inch thick vessels at 3000 psi – far larger than needed, indicating ample capability.
- **Standard Pressure Vessel Components:** e.g. *Generon Custom Vessel.* **Rating:** 15,000 psi (103 MPa) max (they build up to this in smaller diameters); in our size range ~5 m diameter they handle to ~100 bar, but thicker is possible with Div.2. **Code:** ASME VIII (U-stamp). **Supplier:** Generon (Houston, USA) – they list diameters to 5 m, lengths 30 m, thickness 100 mm. **Est. Cost:** on order of $2 M. **Notes:** US-based fabrication, would comply with general pressure vessel standards and could potentially be upgraded to nuclear QA with oversight.
- **SMR Vendor Standard Design:** e.g. *GE Hitachi BWRX-300 RPV by BWXT.* **Rating:** ~7 MPa @ 285 °C (boiling water), but material is same SA-508 class used for PWRs. **Code:** ASME III. **Supplier:** BWXT Canada. **Est. Cost:** (included in first unit contract of CAD 1 B for Darlington) likely ~$40 M. **Notes:** Although BWRX is a BWR, its vessel diameter and wall could be adapted for a PWR of similar thermal output – and GEH explicitly is using proven BWR vessel technology to reduce cost. This indicates that using an established design can save engineering effort. However, we'd still face high fabrication cost for initial units.

In conclusion, **several "off-the-shelf" pressure vessel solutions exist** that could meet the ~15 MPa, 270 °C requirements. The truly off-the-shelf industrial vessels are dramatically cheaper but come with licensing challenges since our project is NRC-regulated (we answered "Yes" to needing NRC compliance). If schedule and budget allow, the safest route is to engage a qualified nuclear supplier (Option A) and attempt to drive cost down via design simplifications (e.g. smaller size, modular internals) and perhaps **competitive bidding among global forge shops**. We could, for instance, solicit quotes from JSW (Japan) and a Chinese forge for the same vessel to negotiate a better price – noting that JSW has targeted the US market and might be eager to supply an SMR vessel. Meanwhile, as a parallel path, we might continue R&D on Options B and D: perhaps fabricate a **Section VIII prototype vessel** to use in a non-nuclear test (e.g. a hydrotest or heat transfer loop) to prove performance, and explore adopting **advanced fabrication** for later units to drastically cut cost. Each option must still satisfy the core constraints defined by the codes and regulations outlined in part 1, but by exploring these multiple strategies, we increase our chances of meeting those requirements **in a more cost-effective way**.

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Kadmos Energy Services LLC

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16. GE Hitachi (GE Vernova) Press Release, Jan 27 2025 – BWRX-300 RPV contract to BWXT (Ontario), highlighting use of **proven components and design** to reduce costsnetp.eugevernova.com.
17. Alibaba Listing – Example *ASME autoclave* pricing: carbon-fiber curing autoclave ~**$14k**oecd-nea.org (illustrates how inexpensive small ASME vessels can be, though not at our high pressure).
18. Shine & Associates (via NRC ADAMS) – **Regulatory Guide 1.50 / 1.99** (not directly cited above) provide guidelines for RPV material toughness and surveillance (relevant to ensure industrial vessel materials can meet these).