

# NUPACK, THE NEW ASME CODE FOR RADIOACTIVE MATERIAL TRANSPORTATION PACKAGING CONTAINMENTS

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## SUMMARY

The American Society of Mechanical Engineers (ASME) has added a new division to the nuclear construction section of its Boiler and Pressure Vessel Code (B&PVC). This Division, commonly referred to as "Nupack," has been written to provide a consistent set of technical requirements for containment vessels of transportation packagings for high-level radioactive materials. This paper provides an introduction to Nupack, discusses some of its technical provisions, and describes how it can be used for the design and construction of packaging components. Nupack's general provisions and design requirements are emphasized, while treatment of materials, fabrication and inspection is left for another paper. Participation in the Nupack development work described in this paper was supported by the U.S. Department of Energy.

## INTRODUCTION

On May 30, 1997 the American Society of Mechanical Engineers (ASME) issued the initial version of Division 3 of Section III of the ASME Boiler and Pressure Vessel Code (B&PVC). Prior to the release of Div. 3, ASME Code Sec. III, which is the Section that applies to nuclear construction, had two divisions: Div. 1 for metal construction and Div. 2 for concrete construction. Div. 3 was added to cover packaging for nuclear materials, hence its common name "Nupack"; however, at this time its scope is limited to containment vessels of transport casks for only the most hazardous radioactive materials, namely spent fuel and other highly radioactive materials such as high-level waste. Moreover, consistent with current ASME Code practice, the concern of this division is primarily the integrity of the vessel under expected and postulated operating conditions. In particular, the operability of the component that the vessel is part of, is not the focus of the ASME B&PVC rules. However, Nupack is concerned with some aspects of vessel closure functionality because seal leakage is a key consideration in the containment function of a transport cask. Div. 3 covers all "construction" aspects of the vessels, which in ASME Code terminology includes materials, design, fabrication, examination, testing and documentation.

The ASME Nupack Group has been active since 1978, pursuing the development of design rules for casks. Initially ASME selected Sec. III, Div. 1, Class 1 of the ASME B&PVC, which is identified as Subsection NB, as the starting point for the Nupack effort. NB is applied to reactor vessels and the primary piping associated with a reactor, which are the most critical components of a nuclear power plant. Among the various component types covered by the ASME Code, the nuclear reactor vessel was judged to be the component most similar to a transportation cask in structural characteristics and design service, as well as in importance to safety. Transportation casks serve as both the containment vessels and the pressure vessels for radioactive material transportation packages. Therefore, the rules for reactor vessels (Subsection NB) appeared to be a good starting point for developing rules for casks. Much later, the ASME Board of Nuclear Codes and Standards decided to give Nupack its own Division (Div. 3) in Sec. III. The new ASME subsection and paragraph designator for packaging containments is WB, corresponding to the NB designator for Nuclear "Class 1" Containments. A general requirements subsection, corresponding to Subsection NCA for Div. 1, is also included and uses the designator WA.

The basic ground rules followed in the development of Nupack were that (1) the new provisions would reflect current practice as accepted by regulatory authorities, and (2) the existing ASME Code provisions would be followed where possible. The first premise meant that the containment vessel design requirements currently imposed by the U.S. Nuclear Regulatory Commission (NRC) and by the U.S. Department of Energy (DOE) would be followed. The second premise results in wording that is copied from the corresponding paragraphs of ASME Code Subsection NB or NCA when the same topics are addressed and the same rules are applicable. The same paragraph numbering is retained wherever possible. Except for a few specific instances that will be described later, these two ground rules did not lead to any conflicts because the NRC recommends using the general approach of ASME Subsection NB through its Regulatory Guide 7.6. It also follows that Nupack has not attempted to write a code that would advance the state of the art of transportation packaging with respect to analytical methods, design criteria, materials of construction, or other aspects. Present activity in the Nupack group is directed in part toward updating Div. 3 to take advantage of current analysis capabilities and materials technologies. Another consequence of the development ground rules is that differences between Subsection NB, with which a nuclear components design engineer may be familiar, and Subsection WB, are not highlighted. The differences are lost in the expanse of Subsections NB and WB so that to apply WB properly, the designer must pay particular attention to the hidden differences between the two Subsections.

The rationale for imposing a set of rules for transportation casks that is as conservative as the rules used for the design of reactor vessels has been questioned by some. The service requirements for casks would appear to be much less severe than those for reactor vessels. After all, in contrast to reactor vessel events, the events taking place inside the casks are not dynamic or highly energetic; they are well-defined and totally predictable. However, it must be recognized that a reactor vessel is always under the control of a trained team of operators, is enclosed in another environment (the containment building that is highly engineered for safety), and is located on a site that has controlled access. On the other hand, a cask traveling down the highway is in an uncontrolled and unpredictable environment, and it is the only barrier between the radioactive material inside and the public, a public that will be sharing the same roadway that the cask is traveling on and usually is not even aware of the cask's presence. On this basis, a cask is considered to be in the same class of importance to safety (Class 1 in ASME Sec. III terminology) as a reactor vessel.

## SCOPE OF NUPACK

The title, and hence the scope, of Div. 3 is containment systems for transport packagings for nuclear spent fuel and high-level radioactive waste. At this time, Div. 3 does not actually define what constitutes spent fuel or high-level waste. This is not a deficiency. The general approach in ASME Sec. III, for example with respect to "Class 1" components, is that it is up to some authority other than the ASME to determine which set of rules applies to any particular component. ASME merely establishes a *consistent* set of rules for each class, rules that presumably provide a uniform and consistent level of safety for components constructed under the rules of any particular class. The practice of the NRC and the DOE is to categorize the severity of radioactive material transport on the basis of the Curies (Becquerels) of the contents, with the limits varying by the radionuclides involved. NRC Regulatory Guide 7.11 and the Draft NRC Standard Review Plan for Transport Packages define the most severe category of contents as that which exceeds 30,000 Ci (1.11 PBq or 1,110 TBq) or 3,000  $A_2$ , where  $A_2$  is derived from the Ci (Bq) level of the specific radionuclides involved, as defined in 10 CFR Part 71 Appendix A and in various IAEA publications. Applying Div. 3 rules to *all* Type B packagings would be more restrictive than current design practice and is not intended by the Nupack group.

Another option for the definition of the scope of packagings to which ASME Sec. III Div. 3 is to be applied would be to use the safety classification scheme in place in ASME Sec. III Div. 1, where rules for three classes of safety, i.e., Class 1, Class 2 and Class 3, are defined. Thus, rather than using a Category I definition, a "Class 1" definition could be applied, possibly consistent with the definition of spent fuel and high-level waste, which may or may not be the same as the currently used special definition of "Category I" described above. At present, the scope definition is up to the packaging owner, who may or may not invoke Div. 3 in his design specification per the guidance of his regulatory authority.

Currently ASME Nupack is interested in expanding its scope in several directions. The first direction would be to cover a wider range of contents, essentially to address all radioactive materials, not just spent fuel and other radioactive materials of a comparable radiological hazard level. There is precedent for this in the current ASME Code structure where various levels of importance to safety are treated as separate "Classes" as noted above. The second direction of expansion could be to address a wider range of packaging components, not just the containment vessel. The third would consider other packaging applications besides transportation, in particular packaging for long-term storage and for multipurpose use such as transportation and storage, for example.

## GENERAL PROVISIONS

The requirements of Div. 3 are organized as general (nontechnical) and technical in Subsections WA and WB, respectively. In comparing WA to NCA, the corresponding Subsection for Div. 1 nuclear plant components, one notes that Div. 3 differs from Div. 1 with respect to the parties addressed by various Code rules. The overall responsibility for Code compliance in Div. 1 rests with the Owner of the nuclear facility, while the fabrication and stamping responsibility rests with the N Certificate Holder. The responsibilities in Div. 3 are necessarily different because overall responsibility cannot be focused on the unique owner for packaging. Typically, packagings of a particular design are owned by one or more organizations, while "ownership" or responsibility for the design can rest with one of these or with some other organization.

The Nupack group dealt with this issue by defining two "owner" parties, the design owner and the packaging owner. Each has a distinct set of responsibilities, and is required to hold a special ASME "Certificate of Accreditation." Earlier versions of Nupack, those drafted before 1992, provided for four responsible parties, defining a Designer in addition to the Design Owner. This reflected the typical arrangement of parties in a cask development project in the USA. However, after review by the main committee of ASME Sec. III, the Designer was eliminated as a separately addressed party and the Designer's responsibilities were assigned to the Design Owner. There were two reasons for this change. It was recognized, first, that the design responsibilities could flow through the Design Owner; and second, that the responsibilities for the inevitable changes to the packaging after it was in service for some time would have had to remain with the Designer, yet the Designer would not necessarily continue to exist as an accessible organization for the long period of time that the packagings of a particular design remained in service. To maintain continuity of responsibility, the design responsibilities had to be placed on the Design Owner.

In terms of current conventional practice in the USA, the Design Owner is the "applicant," i.e., the organization that will apply to the certifying agency, be it NRC or DOE, for certification of the packaging design. The actual designer may be the same organization or an agent or consultant for that organization. As noted, the Design Owner takes responsibility for subsequent changes and for the process of securing Competent Authority revisions to the Certificate of Compliance as needed.

The Packaging Owner, rather than the Design Owner, is responsible for selecting the fabricator and controlling the fabrication process. This includes producing a written agreement with an Authorized Inspection Agency. The fabricator is referred to as the "Class TP Certificate Holder" and is required to have an "N-Type" Certificate of Authorization. As of early 1998, it is not clear that systems are in place to produce the various new ASME Div. 3 mandated certifications, such as: the ASME Certificates of Accreditation for the Design Owner (Applicant); for the Packaging Owner, the certification of an ASME Authorized Inspection Agency for packaging; and, for issuing an ASME N-Type Certificate of Authorization to a Class TP (Transportation Packaging) fabricator.

## DOCUMENTATION REQUIREMENTS

All three parties mentioned in Div. 3 must have a documented quality assurance program and the applicable ASME certificate.

The Design Owner (applicant in packaging terminology) is responsible for three major documents: the Design Specification, the Design Report and the Certificate of Compliance. Div. 3 specifically requires that both the Design Specification and the Design Report be certified by a professional engineer (PE). In addition, the Design Report must receive an independent review, and under the current wording in Div. 3, this independent review is to take place *after* the PE Certification, so it can not be part of the PE Certification process. The packaging community needs to resolve how these documentation requirements, in particular requirements for the Design Report and possibly for the Design Specification, relate to the familiar requirement for a Safety Analysis Report for Packaging (SARP). For many packagings certified under current review procedures, the SARP seems to contain all the information that would be required in a Design Report, and in some cases also the information for a Design Specification.

Additional documents are specified for fabrication of the packaging. The Packaging Owner is responsible for the Construction Specification that must be certified by a PE. The Class TP Certificate Holder, i.e. the fabricator, is responsible for Construction Procedures, Shop Drawings and a Construction Report. In addition, he must produce a Certified Data Report. Current Div. 3 wording calls for "N stamping" of the packaging nameplate or actual vessel. Div. 3 also states that the Design Specification must specify a Code effectivity date that must be no earlier than one year before the date of filing of the Application for the Certificate of Compliance. This is a rather severe requirement. For nuclear reactors the corresponding time period in Div. 1 is three years. However, there is some allowance for materials produced to a different specification date, provided they satisfy the requirements of the same specification that would apply for the Design Specification Code effectivity date.

ASME has an effort underway to segregate technical and administrative requirements. Here "administrative" is interpreted as referring to those requirements whose implementation forces the user of the code to involve an "entity" outside of his organization. Presumably "administrative" would include functionality that is not engineering practice outside of the USA. This should be of interest to firms outside the USA because it would allow a jurisdiction to invoke the technical requirements of the ASME Code without invoking requirements unsuitable outside the USA.

### SPECIFIED LOADING CATEGORIES

The ASME Code, in Sec. III Div. 1 Subsections NCA and NB, establishes a system of loading classification and provides design rules based on these loadings. It provides for *design* loadings, *service* loadings, and *test* loadings. There are four service loading levels, A through D, to which specific service loads can be assigned depending on service and safety requirements, as determined by the owner and specified in the design specification. The ASME Code itself does not assign loads to specific levels. The code also defines the design loading, which is based on the level A service loadings and on other loads that the owner elects to include in this classification by so specifying in the design specification. In addition, the code provides for a hydrotest loading and certain other test loadings.

The Div. 3 (Nupack) rules limit the loadings to only two "service" levels: the normal operating conditions level corresponding to the Div. 1 Level A service, and the hypothetical accident condition level corresponding to the Div. 1 Level D service. In addition, a test loading is defined to cover the hydrostatic test. The concept of a defined set of "nominal" design loadings, as used in Div. 1, is not used in Div. 3. The normal operating condition loadings include both the normal conditions of transport referred to in transportation packaging regulations and the in-plant handling conditions. As is the current packaging practice, the Maximum Normal Operating Pressure (MNOP) is defined as the maximum pressure that can develop in the cask during the period of one year.

Nupack (WB) specifies the hydrotest loading at 150 percent of the MNOP. Div. 1 (NB) uses only 125 percent. The ASME hydrotest is the pressure vessel integrity test and should not be confused with the regulatory containment leak tests called for by 10 CFR Part 71 or by IAEA regulations that are not necessarily performed at high pressure. They should also not be confused with regulatory compliance tests such as the puncture, drop, or fire tests that must meet the ASME Div. 3 Hypothetical Accident Condition limits, not the ASME Div. 3 Test limits.

It is not clear that the Normal Conditions of Transport logically correspond to Level A Service. The contrarian argument is that the one, two or four foot drop (depending on package weight) is not a routinely occurring event but rather the consequence of an upset and hence should be considered a Level B condition. However, Div. 3 treats the Normal Conditions of Transport loadings as Level A Service loadings. This may have come about because of inconsistent usage of the term "normal." In ASME Code Sec. III application to reactor vessels, "normal" refers to conditions that are expected to occur routinely in normal operation. In packaging usage, "normal," as in Normal Conditions of Transport, signifies "worst case" conditions that can be expected to arise during normal operations over the lifetime of a packaging. These are loads after which the packaging is expected to retain full function, and they correspond to loads for which ASME Code Sec. III originally used the term "upset" which was later changed to "Level B Service."

## ALLOWABLE STRESSES

The allowable stress limits in Div. 1 for Level A Service are not significantly more restrictive than those for Level B Service. The difference is that Level A Service Loadings are used to define the design pressure and temperature envelope, whereas the Level B Service Loadings are not. The stress limits used in Div. 3 for Normal Conditions of Transport are the lower (more restrictive) of the limits in Div. 1 for Level A Service and for Design. Thus the Normal Conditions stress "hopper diagram" in Div. 3 is quite different from that for Level A Service in Div. 1. The difference is a result of creating an overlap of the Div. 1 Level A Service limits and the Div. 1 Design limits in producing the Div. 3 Normal Conditions limits.

There is a major difference between the treatment of Hypothetical Accident loadings in Div. 3 and Level D Service loadings in Div. 1, namely, Div. 3 rules do not take advantage of the provisions in Div. 1 for plastic system analysis given in ASME Sec. III Div. 1 Appendix F, in Paragraph F-1340. These provisions are not incorporated because, in packaging, containment is generally provided by seals on contacting flanges, which may be very sensitive to slight deformations; whereas, containment for Div. 1 vessels is based on welded construction that does not exhibit the same sensitivity. Thus, the plastic strain that may be acceptable in Div. 1 may not be acceptable in Div. 3. This is an example of Div. 3 recognizing operability considerations that are not actual vessel integrity concerns.

In applying the basic Level D Service stress limits to the Hypothetical Accident stress limits, the Nupack group incorporated one minor change: Div. 3 limits the primary plus bending stress to 1.00 times the ultimate stress, while Div. 1 allows  $3/2$  of  $0.7$  ( $2/3$ ), which happens to come out to 1.05, times the ultimate stress. At the time Div. 1 was written, ASME apparently considered the 5 percent stress difference insignificant.

Allowable stress limits in the ASME Code are keyed to an elaborate classification of stresses based on the nature of the loading that produces the stress. The rationale for this is that certain stresses, such as those produced by internal pressure, are the result of exogenous causes, while other stresses, such as those at discontinuities, are produced by the resistance of the structure itself to deformation. The first type of stress will remain, even as the structure deforms substantially, whereas the second type of stress is usually reduced as the structure deforms slightly to accommodate the stress and therefore cannot lead to a failure. The Code uses the terms "primary" and "secondary," respectively, to categorize these types of stress. Lower allowable stresses are prescribed for primary stresses. Under the Div. 1 rules, stresses produced by thermal loads are generally treated as the secondary type stress, but that is not

generally the treatment in Div. 3. This difference was incorporated to force the consideration of buckling when two concentric shells are rigidly connected at their ends and subjected to significant differential thermal expansion or thermal gradients. Such a configuration is typical in casks with lead shielding enclosed between two concentric shells. Buckling is generally not a consideration for secondary stresses.

Div. 1 takes advantage of the self-limiting nature of thermal stresses because, as noted above, the ASME Code is generally not concerned with operability. However, the high level of strain needed to reduce thermal load stresses may not be acceptable for a cask. ASME Code Sec. III Div. 1 does recognize potential problems with large thermal load strains by using more restrictive stress limits for certain thermal loadings, whereas an elastic displacement in a large component can cause a large inelastic response in a smaller component. By labeling some thermal stresses as "primary," Div. 3 follows up on this same concern.

Another difference in the Div. 3, as issued in 1997, compared to Div. 1 is in allowable stress levels for bolts. The bolt stresses due to internal pressure plus gasket reaction are treated as normal operating condition loading stresses in Div. 3 and are limited to 2/3 of the yield stress. In Div. 1 these same stresses must pass the design stress limits for bolts that are limited to 1/3 of yield. Thus, under the rules of Div. 3, the nominal tensile stress in the bolts of a vessel under substantial internal pressure could be up to twice that allowed by Div. 1 for the same conditions. It is expected that this inconsistency of Div. 3 with respect to the rest of Sec. III will be corrected. Stress limits for components *other than* bolts do not encounter this difference because, in generating the stress limits "hopper diagram" for normal conditions, Nupack modified the Div. 1 diagram by adding to it the limits for the design conditions. The corresponding modification was not made for the stress limits for bolts. In most cask designs the bolt stresses due to internal pressure and gasket reaction would fall below the 1/3 yield limit because the initial torque loadings are likely to govern bolting design; however, high bolt stresses from pressure plus gasket seating forces can occur in casks with significant internal pressures, and these stresses could govern the design of the bolting system. A design that does not provide a safety factor of three against bolt failure due to normal pressure plus gasket seating loads would not be acceptable under ASME Sec. III Div. 1 rules.

A minor difference between Div. 3 and Div. 1 bolting stress limits is that Div. 3 uses stress intensity for limiting bolt stresses whereas Div. 1 uses nominal stress.

## **MATERIALS, FABRICATION, ETC.**

With respect to materials, Div. 3 generally follows the rules of Div. 1. No new materials have been introduced beyond those sanctioned by Div. 1. The usual Code provisions for introducing new materials apply. Some packaging applications use plate and sheet materials that are relatively thin compared to those in typical Div. 1 applications. In this case, the requirements for volumetric inspection of the base materials that are imposed by Div. 1 will not apply. The same applies to small-diameter piping used for leak test fitting and drain port connections. Also, the paragraphs relating to fracture toughness have been rewritten to reflect more specifically the needs of packaging containments. This will affect the analysis of cask vessels subjected to Hypothetical Accident impact loads.

In Div. 3 the rules for fabrication, installation, examination and testing are almost identical to those in Div. 1. The main changes are those reflecting the deletion of references to piping and valves, and the recognition that for some configurations of casks it is not possible to do

a complete hydrostatic structural integrity test after final assembly of the packaging. This is particularly true when the containment boundary forms part of the cavity for poured-in-place lead shielding.

## CONCLUSIONS

This paper briefly describes the development of the ASME Code Division for nuclear packaging and discusses some of the more interesting decisions related to the scope and contents of this Division, as well as some of the technical requirements related to analysis and design criteria. Because there were many participants with diverse interests, development work within the Nupack group was rather slow and somewhat inconsistent, but an initial release of Div. 3 has finally been achieved. It is a compromise between many needs and the result is not perfect, but now there are opportunities for fine-tuning and expanding this document as future needs become evident and priorities become established.

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**Equipment  
and  
Material**

