ENERCON Excellence—Every project. Every day.	CALCULATION COVER SHEET	CALC. NO. RTL-001-CALC-TH-0102 REV. 1 PAGE NO. 1 of 9

Title:	RT-100 Cask Maximum Normal Operating Pressure Calculation	**Client:**	Robatel Technologies, LLC
		Project:	Robatel002

Item	Cover Sheet Items	Yes	No
1	Does this calculation contain any open assumptions that require confirmation? (If **YES**, Identify the assumptions) Assumption 3 in Section 4.0	☒	☐
2	Does this calculation serve as an "Alternate Calculation"? (If **YES**, Identify the design verified calculation.) **Design Verified Calculation No.** ______	☐	☒
3	Does this calculation Supersede an existing Calculation? (If **YES**, identify the superseded calculation.) **Superseded Calculation No.** ______	☐	☒

Scope of Revision:

Update references and editorial changes

Revision Impact on Results:

N/A

Study Calculation ☐ **Final Calculation** ☒

Safety-Related ☒ **Non-Safety Related** ☐

(Print Name and Sign)

Originator: Hong Sun	**Date:** 10-5-2012
Design Verifier: Amy Varallo	**Date:** 10/5/2012
Approver: John Staples John J Staples	**Date:** 5 oct 2012

ENERCON Excellence—Every project. Every day	CALCULATION REVISION STATUS SHEET	CALC. NO.	RTL-001-CALC-TH-0102
		REV.	1
		PAGE NO.	2 of 9

CALCULATION REVISION STATUS

REVISION	DATE	DESCRIPTION
0	Sept 12, 2012	Initial Issue
1	Oct 5, 2012	Update References and Editorial Changes

PAGE REVISION STATUS

PAGE NO.	REVISION	PAGE NO.	REVISION
1-8	1		
9	0		

APPENDIX REVISION STATUS

APPENDIX NO.	PAGE NO.	REVISION NO.	APPENDIX NO.	PAGE NO.	REVISION NO.

Calculation Design Verification Plan:

Calculation to be reviewed for correctness of inputs, design criteria, analytical methods, acceptance criteria and numerical accuracy.

Stated objectives and conclusions shall be confirmed to be reasonable and valid.

Any assumptions shall be clearly documented and confirmed to be appropriate and verified based on sound engineering principles and practices.

NOTE:

This calculation contains an Open Item concerning the confirmation of the hydrogen generation rate of the content for each shipment. Engineering control should be performed to ensure this criterion is met for each shipment.

(Print Name and Sign for Approval – mark "N/A" if not required)

Approver: **John Staples** John 7 Staples	**Date:** 5 Oct 2012

Calculation Design Verification Summary:

Calculation has been designated as **Safety Related** as noted on the cover sheet.

Calculation has been verified to be mathematically correct and performed in accordance with appropriate design inputs, assumptions, analytical methods, design criteria and acceptance criteria.

The conclusions developed in the calculation are reasonable, valid and consistent with the purpose and scope.

Assumptions are appropriate and correct.

NOTE:

This calculation contains an Open Item as described in Assumption 3. Engineering control should be performed to ensure the hydrogen generation rate of the content for each shipment met this criterion.

Based On The Above Summary, The Calculation Is Determined To Be Acceptable.

(Print Name and Sign)

Design Verifier: **Amy Varallo**	**Date:** 10/5/2012
Others:	**Date:**

ENERCON Excellence—Every project. Every day.	CALCULATION DESIGN VERIFICATION CHECKLIST	CALC. NO.	RTL-001-CALC-TH-0102
		REV.	1
		PAGE NO.	4 of 9

Item	CHECKLIST ITEMS	Yes	No	N/A
1	**Design Inputs -** Were the design inputs correctly selected, referenced (latest revision), consistent with the design basis, and incorporated in the calculation?	X		
2	**Assumptions** - Were the assumptions reasonable and adequately described, justified and/or verified, and documented?	X		
3	**Quality Assurance** - Were the appropriate QA classification and requirements assigned to the calculation?	X		
4	**Codes, Standards, and Regulatory Requirements** - Were the applicable codes, standards, and regulatory requirements, including issue and addenda, properly identified and their requirements satisfied?	X		
5	**Construction and Operating Experience** - Have applicable construction and operating experience been considered?	X		
6	**Interfaces** - Have the design-interface requirements been satisfied, including interactions with other calculations?	X		
7	**Methods** - Was the calculation methodology appropriate and properly applied to satisfy the calculation objective?	X		
8	**Design Outputs** - Was the conclusion of the calculation clearly stated, did it correspond directly with the objectives, and are the results reasonable compared to the inputs?	X		
9	**Radiation Exposure** - Has the calculation properly considered radiation exposure to the public and plant personnel?			X
10	**Acceptance Criteria** - Are the acceptance criteria incorporated in the calculation sufficient to allow verification that the design requirements have been satisfactorily accomplished?	X		
11	**Computer Software**- Is a computer program or software used, and if so, are the requirements of CSP 3.02 met?			X

COMMENTS

(Print Name and Sign)		
Design Verifier: **Amy Varallo**		**Date:** 10/5/2012
Others:		**Date:**

Table of Contents

1.0 PURPOSE AND SCOPE

Robatel Technologies is designing the RT-100 transport cask to transport radioactive waste in the form of dewatered resins and filters. The RT-100 transport cask is required to meet the requirements of 10 CFR Part 71 (Ref. 3.1). The purpose of this calculation is to calculate the cask cavity Maximum Normal Operating Pressure (MNOP) for the cask under the Normal Conditions of Transport (NCT).

2.0 SUMMARY OF RESULTS AND CONCLUSIONS

A pressure of 342.7 kPa [49.7 psia] is recommended for use in the cask analysis under normal conditions of transport (NCT) requiring MNOP.

3.0 REFERENCES

3.1 Nuclear Regulatory Commission, 10CFR Part 71, "Packaging and Transportation of Radioactive Material"

3.2 J. Chang, P. Lien, and M. Waters, Evaluation of Hydrogen Generation and Maximum Normal Operating Pressure for Waste Transportation Packages, WM2011 Conference, Feb 27 – Mar 3, 2011, Phoenix, AZ

3.3 ENERCON Calculation RTL-001-CALC-TH-0201 Rev. 01, "RT-100 Cask Thermal Analyses"

3.4 Fundamentals of Engineering Thermodynamics, 5th Edition, M. Moran and H. Shapiro

3.5 Fundamental of Fluid Mechanics, 4th Edition, B. Munson, D. Young and T. Okiishi

4.0 ASSUMPTIONS

(1) Ideal gas law is used to calculate the cask cavity pressure at a given temperature. The content inside the cask is dewatered resins and filters, water amount is very limited. Air occupies the cask cavity. The gas within the cask, a mixture of air, water, oxygen, and hydrogen generated through radiolytic decomposition of the water residual, behaves as an ideal gas, and the ideal gas law is used to calculate the change in pressure due to change in temperature.

(2) The cask at the time of loading has an internal pressure equal to ambient pressure, which is assumed to be 1 atm absolute (101.35 kPa, 14.7 psia) at 21.1 °C (70 °F, 294.25 K).

(3) **Open Assumption**: The amount of hydrogen generated inside the cask cavity is not greater than 5% by volume.

The shipper needs to confirm for each shipment that the content will not generate hydrogen greater than 5% of the cavity volume for flammability concerns.

There are no unverified assumptions in this calculation. Other design assumptions used, if any, will be noted and referenced as needed in the body of the calculation.

5.0 DESIGN INPUTS

5.1 Temperature

Initial temperature of the gas in the cask = 21.1 °C (See Section 4.0)
Final temperature of the gas = Maximum internal cask temperature (Ref. 3.3)
= 80 °C [353.15 K, 176 °F] (Upper Bound)
= -29 °C [244.15 K, -20.2 °F] (Lower Bound)

5.2 Pressure

Initial pressure of the gas in the cask = 1 atm abs. [14.7 psia, 101.35 kPa] (See Section 4.0)

6.0 METHODOLOGY

To determine the MNOP, the temperature of the gas mixture within the cask is evaluated. The maximum temperature of the cask cavity under normal condition is bounded by upper and lower temperature range of 80 °C to -29 °C (See Section 5.1).

The maximum pressure is the sum of three components:

1. the pressure due to air in the cavity;
2. the pressure due to water vapor in the cask; and
3. the pressure due to the gas (hydrogen and oxygen gases generated) by radiolysis.

The restriction of the contents to inorganic materials eliminates the potential for gas generation due to thermal degradation or biological activity. Thus, these gas sources are not considered in the evaluation.

Per the ideal gas law, air pressure and water vapor pressure are directly proportional to the temperature and with an increase in temperature, the total pressure also increases. Thus, upper bound temperature will result in a higher maximum normal operating pressure for the cask compared to lower bound, so the gas mixture in the cavity is conservatively assumed to be 80 °C.

7.0 CALCULATIONS

7.1 Pressure Due to the Increased Temperature of the Gas Initial Air in the Cavity

Per the ideal gas law, the increased partial pressure of the air (P_{air}) initially sealed in the fixed volume of the cask at the ambient temperature as it is heated to 80 °C is:

P1xT2 = P2xT1 (Ref. 3.4)

P_{air} = 101.35 kPa[(353.15 K) / (294.25 K)] = 121.64 kPa (17.64 psia)

7.2 Pressure Due to the Water Vapor in the Cask

The cask cavity is assumed to contain a small amount of water. Thus, conservatively assuming a condensing surface temperature of 80 °C, the water vapor pressure, P_{wv}, at this temperature is 47.36 kPa [6.87 psia] (Ref. 3.5, Table B.1).

Adding the water vapor pressure at 80 °C to the partial pressure of the air in the sealed cask at this temperature gives:

Pressure $P_2 = P_{air} + P_{wv} = 121.64 + 47.36 = 169.0$ kPa [24.51 psia]

7.3 Pressure Due to Generation of Gas

Solid inorganic materials have a G value of zero, i.e., solid inorganic materials do not generate hydrogen or other gases through radiolysis. Solidified or dewatered material may contain some water and, if the cask is loaded underwater, a small amount of water may remain in the cavity after draining. The radiolytic generation of gases is limited to the radiolysis of this residual water. Hydrogen and oxygen may be produced in the cask by radiolytic decomposition of residual water in the cask contents. The amount of hydrogen generated in the cask cavity must not be greater than 5% by volume for the contents that include water (Open Assumption). Hence, the cask atmosphere is assumed to contain five volume percent of hydrogen (H_2) gas due to radiolysis of the water. By stoichiometry of the water molecule (H_2O), the cask atmosphere will also contain 2.5 vol. % oxygen (O_2) gas generated by radiolysis. Noting that partial pressures in an ideal gas mixture are additive and behave the same as ideal gas volume fraction or mole fractions, the partial pressure of hydrogen is described by the following equation:

$P_{H2} = 0.05\ P_{pt}$

Where, $P_{pt} = P_{air} + P_{wv} + P_{H2} + P_{O2}$

Combining $P_{air} + P_{wv} = P_2$ per Section 7.2, and noting that $P_{O2} = 0.5 \times P_{H2}$.

$P_{H2} = 0.05 \text{ x } (P_2 + 1.5\ P_{H2})$

Solving the equation explicitly for P_{H2} gives:

$$
\begin{aligned}
P_{H2} &= [0.05\ P_2] / [1 - 0.05\ (1.5)] \\
&= [0.05 * 169.0 \text{ kPa}] / [1 - 0.05\ (1.5)] \\
&= 9.14 \text{ kPa } [1.32 \text{ psia}]
\end{aligned}
$$

7.4 Total Pressure

Based on the stoichiometric relationship between hydrogen and oxygen liberated by radiolysis of water, and again combining the pressure of the initially sealed air and water vapor as P_2, the total pressure in the cask at 80 °C is:

$$
\begin{aligned}
P_{Total} &= P_2 + 1.5\ P_{H2} \\
&= 169.0 \text{ kPa} + 1.5 * 9.14 \text{ kPa} \\
&= 182.71\text{kPa } [26.5 \text{ psia}]
\end{aligned}
$$

The MNOP value is conservatively set at 342.7 kPa [49.7 psia] for use in the cask analysis under normal conditions of transport (NCT).