Project No Y14/07/05	**Design/Drawing No HS 3977A**
Maximum Pressure in Containment Vessel 3978 Under NCT and HAC With I-131 Contents	See WI 03-04 for guidance

1 Objective

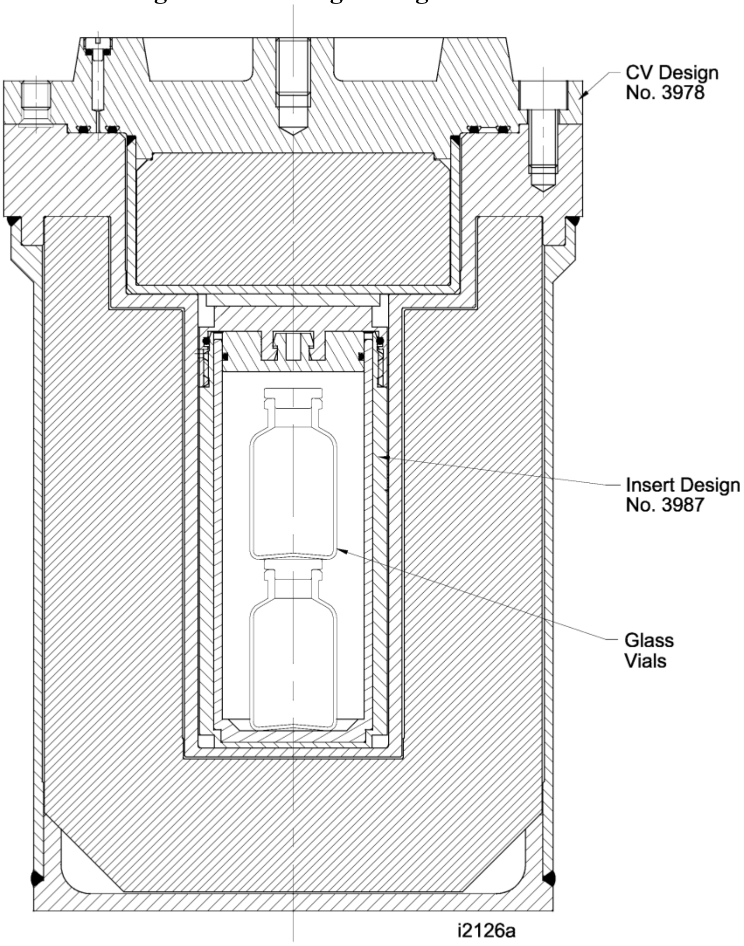
To determine the maximum pressure in the CV under normal conditions of transport (NCT) and Hypothetical Accident Conditions (HAC) when loaded with up to 200 Ci of I-131.

2 Calculation Model NCT

2.1 Initial Loading Conditions

The I-131 is carried in two 20 ml (nominal) Schott lnjektion Type I Plus vials as shown in Figure 1. The total free volume in the CV cavity corresponds to the free volume inside the insert, product vials, the free volume that surrounds the insert and the volume around the containment vessel lid up to the seals. This free volume equates to 216 cm^3. The contents are loaded in a hot cell at 20^{o}C. The contents are allowed a maximum heat load of 5W which leads to a maximum temperature in the stainless steel insert of 80^{o}C. However 200 Ci of I-131 only produces 0.656W therefore the actually temperature will be much lower.

Figure 1 - Loading arrangement for I-131



2.2 Methods of Pressure Generation

Within the package there are 4 methods by which pressure can increase:

- Radiolysis
- Radioactive Decay
- Temperature increase
- Water vapour pressure

The effect of each has been determined and the maximum pressure under NCT calculated.

Radiolysis

I-131 liquid contents generate hydrogen due to radiolysis. The I-131 producer has carried out experiments to validate the calculation method used to determine the radiolytic gas generation of the I-131 solution contained in the glass vials shown in Figure 1[1]. Calculations using this method demonstrated that 2 vials produced 106.8 cm^3 of hydrogen over 10 days[2]. In order to determine the pressure this volume of gas produces the number of moles present is calculated using the ideal gas law where

$$n = \frac{P \times v}{R \times T}$$

n = Number of moles

P = Pressure (Pa)

V = volume (m^3)

R = Universal gas constant 8.31 (J/mol K)

T = Temperature (K)

$$n = \frac{101325 \times 1.07 \times 10^{-4}}{8.31 \times 298} = 4.37 \times 10^{-3}$$

Therefore the pressure in the CV free volume at STP is:

$$v = \frac{n \times R \times T}{p} = \frac{4.37 \times 10^{-3} \times 8.31 \times 298}{2.16 \times 10^{-4}} = 5 \times 10^{4} Pa$$

$5x10^4$ Pa = 0.5 Barg

Along with the radiolysis of the contents gamma irradiation is also shown to cause the generation of gas in PTFE. The liner is the only PTFE material used other packing material would be LDPE which is shown to have good radiation resistance[3].

The volume of gas generated from radiolysis can be calculated using:

$V_g = D \times G \times v / A_n$ **Eqn. 1**

Where:

$\mathbf{V_g}$ is the volumetric gas generation rate in cm^3/sec at standard pressure and temperature. Using an integrated dose allows for a direct calculation of gas production.

D is the rate of energy absorbed in the PTFE (MeV/sec). The dose received by the PTFE over the 10 day shipment time has been calculated in a MURR report[4]. This report calculated an average dose of 43 kGy and a maximum dose point of 147 kGy in the liner. To allow a factor of Safety we will assume an average dose rate of 147 kGy. There is 112g of PTFE in the stainless steel insert.

G is the "g-value" for the production of molecules of hydrogen per unit of energy deposited. This G value has been taken from a paper in the Journal of Research[5]. The largest G value calculated for PTFE under gamma radiation was 3200 molecules/MeV.

v is the volume of 1 mole of gas at STP (2.24×10^4 cm^3/mole)

$\mathbf{A_n}$ is Avogadro's number (6.023×10^{23} molecules/mole)

Using equation 1 the gas production of the PTFE shall be 12 cm^3.

In order to determine the pressure this volume of gas produces the number of moles present shall be calculated using the ideal gas law where

$$n = \frac{P \times v}{R \times T}$$

$$n = \frac{101325 \times 1.22 \times 10^{-5}}{8.31 \times 298} = 5 \times 10^{-4}$$

Therefore the pressure in the CV free volume at STP is:

$$v = \frac{n \times R \times T}{p} = \frac{5 \times 10^{-4} \times 8.31 \times 298}{2.16 \times 10^{-4}} = 5.73 \times 10^3 Pa$$

5.73×10^3 Pa = 0.0573 Barg

Therefore due to Dalton's law of partial pressures the pressure in the CV due to radiolysis is:

0.5+0.0573=0.56 Barg

<u>Radioactive Decay</u>

I-131 decays to form Xe-131 a gas. Over the 10 day transit time I-131 would decay to form 1.06×10^{-5} moles of Xe gas. At 80°C this would create a pressure of 1.44×10^{-6} barg. Therefore the pressure due to Xe can be neglected in these calculations.

Temperature Increase

During the normal condition of transport the insert will reach a maximum temperature of 80°C. If we assume that all the gases in the package along with the air present during the initial loading then the pressure in the package will increase according to the ideal gas law. The pressure of the radiolysis gases will be:

$$P_2 = P_1 \times \frac{T_2}{T_1}$$

Where T_2 = 353 K (80°C)
T_1 = 293 K (20°C)
P_1 = 1.56 bara

$$1.56 \times \frac{353}{293} = 1.88\ bara$$

The air already present in the CV cavity is at atmospheric pressure on loading which is 1 bara, therefore the pressure of the air at 80°C is:

$$1 \times \frac{353}{293} = 1.20\ bara$$

Therefore the total pressure due to heating of the contents will be 1.88+1.20=3.08 bara

Water Vapour pressure

Water vapour at 80°C is given in steam tables as 0.6 bara.

Therefore the maximum pressure in the CV under NCT is 3.08+0.6=3.68 bara =2.68 barg.

3 Calculational Model under HAC

During HAC the maximum temperature reached by the insert is 134°C (407 K). If we assumed that all the gases apart from the water vapour are heated to this temperature then according to Boyles Law the pressure in the CV would be:

$$P_{HAC} = P_{NCT} \times \frac{T_{HAC}}{T_{NCT}}$$

$$2.68 \times \frac{407}{353} = 3.09\ barg$$

The vapour pressure of the solution at 134°C is 3 bara, therefore the pressure in the CV is 3.09 + 2 = 5.09 barg using Dalton's law of partial pressures.

The hydrogen generation rate has not been increased to account for the HAC temperatures because HAC temperatures would exist for a relatively short time.

Role	Name	Role	Signed	Date
Prepared	Sarah Bryson	Licensing Engineer		20 Feb 17
Checked	Bob Vaughan	Director		20 Feb 17
Approved	Bob Vaughan	Director		20 Feb 17

4 References

[1] Additional Contents Request for Croft Packaging, Model 3977A (SAFKEG -HS), 29 August 2014
[2] Additional Contents Request for Croft Packaging, Model 3977A (SAFKEG -HS), 19 July 2016
[3] https://ab-div-bdi-bl-blm.web.cern.ch/ab-div-bdi-bl-blm/Radiation/Gamma_Compatible_Materials_List_company.pdf
[4] HS SS-Insert Radiation Doses in PTFE, William H Miller, December 5, 2016.
[5] Journal of Research of the National Bureau of Standards – A Physics and Chemisty Vol 65A, No 4 July-August 1961, Gamma Irradiation of Fluorocarbon Polymers, Roland E Florin and Leo A Wall.