0.1 SAR REVISION STATUS

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0.2 SUPPORTING DOCUMENT REVISION STATUS

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1C-5999	Issue A	Containment Vessel HS Body Construction
3C-6850	Issue A	HS-12x95-Tu Insert Design No.3982 (construction)
3C-6851	Issue A	HS-31x114-Tu Insert Design No. 3985 (construction)
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0C-5942	Issue C	Keg design no. 3977 (licensing drawing)
0C-5943	Issue B	Cork set for Safkeg-HS (licensing drawing)
1C-5944	Issue C	Containment vessel design no. 3978 (licensing drawing)
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2C-6173	Issue D	HS-12x95-Tu Insert Design No 3982 (Licensing drawing)
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2C-6176	Issue E	HS-55x128-SS insert design no 3987 (licensing drawing)
2C-6920	Issue A	Silicone Sponge Rubber Disc
1C-7500	Issue B	Cover sheet for Safkeg-HS design no. 3977A - Mallinckrodt Version
0C-7501	Issue B	Safkeg-HS design no. 3977A - Mallinckrodt Version
0C-7502	Issue A	Keg design no. 3977 - Mallinckrodt Version
0C-7503	Issue A	Cork set for Safkeg-HS - Mallinckrodt Version
1C-7504	Issue A	CV design no. 3978 - Mallinckrodt Version

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SERCO/TAS/002762/01	Issue 1	Compression Testing of Cork
Vectra, L20008/1/R1	Rev 0B	Stress Analysis of Safkeg HS 3977A Containment Vessel
CS 2012/02	Issue A	SAFKEG HS 3977A – Maximum Pressure in CV
CS 2012/03	Issue A	SAFKEG HS 3977A – Package Density
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CS 2012/01	Issue A	SAFKEG HS 3977A – Maximum Temperature of CV Inserts
CS 2016/31	Issue A	Maximum Pressure in Containment Vessel 3978 Under NCT and HAC
MURR Report		Hydrogen Generation Analysis – MURR Technical Note
MURR Report	2 Apr 16	Analysis Of The Possibility Of, And Consequences From, Hydrogen Deflagration And Detonation Resulting From Radiolysis-Produced Hydrogen In An Iodine-131 Radiopharmaceutical Solution
MURR Report	19 Jul 16	Additional Contents Request for Croft Packaging, MURR
CS 2016/27	Issue A	Temperature of Mo-99 Contents in the HS Package

Page/Document Reference	Issue Status	Title
Mallinckrodt Report	V2.2	Radiolytic Gas Formation in Mallinckrodt Produced Mo99 Solutions
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CS 2012/05	Issue A	SAFKEG-HS 3977A - Gas contents limit for leaktight condition
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CTR2011/01	Issue D	SAFKEG HS 3977A: Package Activity Limits Based on Shielding
CTR2013	Issue C	Uncertainties Associated with the Proposed Shielding Calculation Method for the SAFKEG-HS 3977A Package
AMEC/SF6652/001	Issue 2	Monte Carlo Modelling of Safkeg HS Container

Page/Document Reference	Issue Status	Title
AMEC/CRM37327/TN_001	Issue 1	HS Container Shielding Assessment with I-131
AMEC/CRM37327/TN_001	Issue 1	HS Container Shielding Assessment with Mo-99
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3.3.2 Maximum Normal Operating Pressure [71.33 (b)(5)]

The MNOP is 7 bar (700 kPa) gauge.

For solid contents emitting 30W, under NCT the maximum temperature of the CV is 163°C and the maximum temperature of the Shielding Insert and air within the CV is 173°C. Assuming the content were loaded at 20°C and a pressure of 1 bar abs, the pressure at the maximum temperature of the Shielding Insert, calculated according to Boyle's and Charles' Laws, would be 1.63 bar (163 kPa) gauge (see Calculation Sheet CS 2012/02),which is well within the design envelope.

With regards to the liquid content the maximum normal operating pressure is calculated using the maximum temperature during NCT, the free volume of the containment vessel cavity and vials and all possible sources of gas generation and gases that are present on loading the containment vessel. For I-131 this includes gases present in the CV on loading, Xe-131 generation and radiolytic decomposition over a 28 day period.

For the I-131, under NCT maximum temperature of the CV is 78°C and the maximum temperature of the Shielding Insert and air within the CV is 80°C. (Section 3.1.3, Table 3-1). There is no pressure increase due to the vapour pressure of the liquid contents (the liquid contents are aqueous with a boiling point of 100°C) as the temperature is < 100°C.

The maximum free volume of the containment vessel cavity is 216 cm^3. This corresponds to the free volume that surrounds the insert, the volume around the containment vessel lid up to the seals and the free volume inside the insert and product bottles.

MURR have conservatively calculated that each I-131 vial will generate 89 cm^3 of Hydrogen over 28 days as detailed in the technical note listed in section 3.5.2. If 2 vials are shipped this equates to 178 cm^3 of hydrogen. In a free volume of 216.4 cm^3 along with heating of the gases on loading this would lead to a MNOP of 1 barg, which is below the design pressure of 7 barg. The generation of Xe-131 only leads to an increase in pressure of $4x10^{-6}$ bar, therefore it can be neglected from the calculation of the MNOP. MURR are limiting shipment time of I-131 to 10 days therefore the MNOP will be lower than 1 barg calculated.

For Mo-99 the maximum temperature of the contents within the insert is 84.56°C as calculated in CS 2016/28 (section 3.5.2). This temperature assumes a constant 5W heating over the course of a year, however in reality the thermal power of the contents decreases over time. The maximum free volume of the containment vessel is 233 cm^3. This corresponds to the free volume inside the insert, product bottle, the free volume that surrounds the insert and the volume around the containment vessel lid up to the seals.

Pressure will build up in the CV via radiolysis, heating of the gases in the CV and saturated vapour pressue. The Mo-99 contents generate hydrogen due to radiolysis. The Mo-99 producer has carried out experiments, to determine the radiolytic gas generation of the Mo-99 solution contained in the stainless steel bottles described in section 1 of this SAR.

Using this information and taking into account all these mechanisms the highest pressure was calculated in CS 2016/31 (section 3.5.2), this was 5.97 barg for a solution with an activity of 60 Ci/ml and a dispensed product volume of 16.667 ml. This pressure is below the bounding maximum pressure for NCT operating conditions.

The bounding temperatures and pressures for the package are as follows.

NCT Operating Condition	CV
Assumed Max. Temperature	160°C
Max. Pressure	800kPa (8.0 bar) abs
Min. Temperature	-40°C
Min. Pressure	0 kPa (0 bar) abs

The producer of the Mo-99 performed mass spectrometer measurements of the gas samples obtained during the radiolytic gas generation calculations. Of the 2 samples tested the results were 1.8% and 0.8% hydrogen by volume of the pure evolved gas. This is an average of 1.3%, with a 2σ uncertainty of 1.4%. So the concentration of hydrogen in the pure evolved radiolysis product is conservatively estimated to be 2.7% by volume. This is well below 5% by volume and therefore does not constitute a risk of flammability or ignition.

The hydrogen generation calculations for the I-131 contents for a shipment time of 10 days indicate the hydrogen concentration is 26%. Under normal conditions of transport (NCT) all hydrogen will be trapped in the product container within the insert, and no source for ignition exists. If somehow the product container fails, and the hydrogen escaped into the insert, and then the insert were to leak as well, into the containment vessel, and somehow ignition were to occur, the total energy release would be less than 966 Joules (231 calories).

The energy content of combustion of evolved hydrogen is negligible compared to the heating of the cask from the decay of I-131. For example, the decay heating rate of 200 Ci of I-131 was previously calculated to be 0.656 watts or 0.656 J/sec which would release 966 Joules of energy in less than one-half hour. Thus, the heating created by ignition of all of the hydrogen generated over 10 days would be negligible compared to the heating of the package by the decay of I-131.

These calculations and experiments indicate that hydrogen ignition in the case of I-131 liquid contents is not a credible source of risk to the public, see section 3.5.2.

3.4 Thermal Evaluation under Hypothetical Accident Conditions

3.4.1 Initial Conditions

The initial conditions used for the thermal model of the fire test are taken at the end of a 12 hour period of insolation under Normal Conditions of Transport with a content decay heat of

3.5.2 Supporting Documents

Document Reference	Title
AMEC/6335/001	Thermal Analysis of the SAFKEG HS Design
CS 2012/01	SAFKEG-HS 3977A – Maximum temperature of CV inserts
CS 2016/31	Maximum Pressure in Containment Vessel 3978 Under NCT and HAC
	Hydrogen Generation Analysis – MURR Technical Note
	Analysis Of The Possibility Of, And Consequences From, Hydrogen Deflagration And Detonation Resulting From Radiolysis-Produced Hydrogen In An Iodine-131 Radiopharmaceutical Solution
	Additional Contents Request for Croft Packaging, MURR, 19th July 2016
CS 2016/27	Temperature of Mo-99 Contents in the HS Package
V2.2	Radiolytic Gas Formation in Mallinckrodt Produced Mo99 Solutions