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Case No: 2004 FOLIO 934

IN THE HIGH COURT OF JUSTICE
QUEEN'S BENCH DIVISION
COMMERCIAL COURT

Royal Courts of Justice
Strand, London, WC2A 2LL

Date: 24/07/2009

Before :

MR JUSTICE CHRISTOPHER CLARKE

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Between :

COMPANIA SUD AMERICANA DE VAPORES S.A.	**Claimant**
- and -	
SINOCHEM TIANJIN IMPORT AND EXPORT CORP	**Defendant**

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Simon Rainey QC & Ruth Hosking (instructed by **Holman Fenwick Willan**) for the **Claimant**
Robert Bright QC & Anna Gotts (instructed by **Reed Smith LLP**) for the **Defendant**

Hearing dates: 4th, 11th, 12th, 16th, 17th, 18th, 19th, 23rd, 24th and 31st March and 1st April 2009

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Judgment

MR JUSTICE CHRISTOPHER CLARKE :

1. At about 0230 local time on 30th December 1998 an explosion took place in the No 3 hold of the m.v. "Aconcagua" when she was on passage off the coast of Ecuador. The fire which resulted was so great that the crew had to abandon ship. Widespread damage was caused to the vessel and her cargo.

2. The cause of the explosion was the self ignition of 334 kegs of calcium hypochlorite stowed in a container ("the container"). The container had been loaded at Busan, South Korea and was due to be discharged at San Antonio in Chile. The vessel was on time charter to Compania Sud Americana de Vapores S.A ("CSAV"), a Chilean company, the now claimant. The owners of the vessel - MS ER Hamburg Schiffahrtsgesellschaft Mbh & Co ("the Owners") – commenced an arbitration under the charterparty against CSAV. They held it responsible for the explosion and their consequent loss, claiming damages or an indemnity. The arbitration proceeded to an interim award in which the arbitrators decided certain issues, after which CSAV reached a settlement with the Owners pursuant to which they paid them US $ 27,750,000.

The parties' contentions - Overview

3. CSAV now claims damages against the shippers of the calcium hypochlorite, Sinochem Tianjin Import and Export Corp ("Sinochem"), for breach of the contract contained in or evidenced by the bill of lading in respect of the container. It seeks to recover the amount which it paid the Owners in settlement and the costs of defending the Owners' claim in addition to the amounts that it had counterclaimed in the arbitration. Sinochem is a Chinese State-owned trading house, which supplies many different chemicals and which is the Tianjin based company in a large group of other Sinochem companies.

4. Calcium hypochlorite is a dangerous cargo for the reasons set out in paras 41 ff below. CSAV claims that this particular cargo had, unknown to it, an abnormally high thermal instability, being prone to self-heat at ordinary carriage temperatures. As a result it exploded on board the "Aconcagua" at temperatures which were ordinarily to be expected onboard that vessel during this voyage. If it had not been abnormal (or "rogue") it would not have done so and any self heating would have been negligible. CSAV claims compensation for its losses under Article IV, Rule 6 of the Hague Rules. Sinochem contends that the cargo shipped was not abnormal or, at the lowest, has not been shown to be so.

5. The cargo was stowed in a position where it was surrounded on three sides (forward, base and outboard side) by a bunker tank – No 3 FFOTS[1]. That tank was heated during the voyage in order to allow the transfer of bunkers to one of two settling tanks for fuel oil in the engine room. The stowage of the container in that position is admitted by CSAV to have been negligent. The

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[1] Forward Fuel Oil Tank Starboard

relevant International Maritime Dangerous Goods ("IMDG") Code requires the cargo to be stowed "*away from*" sources of heat. When heated the bunker tanks were sources of heat. Sinochem contends that the heating of the bunker tank on the voyage was either *the* or *a* cause of the explosion; that the bad stowage of the container and its contents amounted to unseaworthiness; and that, even if the cargo was a rogue cargo, CSAV is not entitled to any relief under Article IV, Rule 6 because it had failed to take due care to make the vessel seaworthy.

6. CSAV contends that the stowage of the cargo next to a bunker tank which was heated on the voyage was of no causative significance. The contribution made by the heating of the bunker tank to the warming of the container and its contents was wholly insufficient to have had any significant effect on, and made no difference to, the outcome. The explosion occurred when the vessel was, and had been for some 6-7 days in tropical waters. As a result the temperatures which the calcium hypochlorite (CH) would have experienced *without heating* were sufficient to cause an explosion in this material, but not in normal material. Further, or alternatively, if the container had not been stored where it was, it could and would properly have been stored somewhere away from No 3 FFOTS in which position the explosion would still have occurred.

7. In any event, CSAV contends, when the vessel was loaded at Busan in Korea, bound for South America, she was not unseaworthy. If heat from No 3 FFOTS was of any causative significance that only arose when the heating took place as a result of a decision of the Chief Officer to use and heat that tank as opposed to others available. His negligent decision to heat a bunker tank adjacent to a cargo of calcium hypochlorite does not mean that the vessel was unseaworthy at the commencement of the relevant voyage (Busan to San Antonio). In addition his decision was "*an act, neglect or default in the management of the vessel*" for which CSAV is not responsible by virtue of Article IV Rule 2 (a) of the Hague Rules.

The evidence

8. The witnesses of fact who were called to give evidence were (i) Dr Paul Beeley, who also gave expert evidence, and (ii) Mr Julian Clark of HFW on behalf of CSAV; and (iii) Mr Wang Fei on behalf of Sinochem. Dr Beeley had been instructed as an expert witness for the Owners in the arbitration and Mr Clark (then at Clifford Chance) had acted for CSAV in the dispute with Owners. Written evidence was adduced by CSAV from the members of the crew of the "Aconcagua" referred to in para 13 below and Captain Hector Araya, CSAV's operations Manager Asia and Bulk Director.

9. Most of the evidence adduced at the hearing consisted of expert evidence from the following:

For CSAV:

(i) Professor Gray who is the Emeritus Professor of Chemistry at Macquarie University, Sydney, New South Wales and a Visiting Professor at the Computational Fluid Dynamics Centre at the University of Leeds; he has done extensive research in, inter alia, combustion, ignition and explosion theory.

(ii) Dr Paul Beeley, who in 1998 was a partner in Dr J H Burgoyne and Partners ("Burgoynes"), and now operates his own consultancy;

For Sinochem:

(iii) Mr Mark Phillips of Burgoynes;

(iv) Mr Graham Charlton, also of Burgoynes.

That evidence, particularly from Professor Gray and Mr Phillips, was both extensive and complex.

10. In order to address the issues of which I have given an overview it is necessary to set out a considerable amount of detail.

The vessel

11. The m/v "ACONCAGUA" is a 2,226 TEU fully-cellular container vessel built by China Shipbuilding Corporation in Kaohsiung, Taiwan. She was a new build and left the shipyard on 15th September 1998. The vessel had 5 holds forward of her engine room and accommodation. Hold No. 1 was designed to accommodate 40' cargo containers stowed longitudinally. Hold Nos. 2, 3, 4 and 5 were divided into forward and aft sections by transverse partial bulkheads. Each section was long enough to accommodate one 40' or two 20' shipping containers. All holds aboard the vessel were certified for the carriage of dangerous goods falling within Class 5.1 of the International Maritime Dangerous Goods ("IMDG") Code. The vessel was operated by CSAV in their Asia Andes ("ANDEX") liner service operated jointly with NYK.

12. Water ballast was carried in double bottom tanks. The vessel also had side heeling tanks in way of the No. 4 hold. The fuel oil tanks on the vessel include No. 3 AFOT (P&S) and No. 3 FFOT (P&S)[2]. These tanks represent the port and starboard sides of the hold. Additional bunker tanks were No 2 FOT (P & S) located in the bulkhead between Nos. 2 and 3 cargo holds, and No 4 FOT (P & S), which were deep tanks built into the bulkheads between holds 4 and 5. All the fuel oil tanks could be heated by the use of steam heating coils, whose control valves were located at the forward bulkhead of

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[2] Aft and Forward Fuel Oil Tanks (Port and Starboard).

the engine room. The bunker tanks are fitted with remote read-out level gauges.

13. On the voyage in question the Master was Captain Andreas Horber. The Chief Officer was Mr Philipp Dieckmann. The Chief Engineer was Mr Wolfgang Gruener. The 3rd Engineer was Mr Christian Obst. The 1st Assistant Engineer was Mr Roy Muzones.

The contractual documents

Charterparty

14. CSAV was the charterer under a time charterparty dated 21st May 1998 on an amended NYPE 1946 form for 40-51 months. The vessel was to be taken over from the yard where she was being built in Taiwan. Clause 8 of the Charterparty provided that :

> *"Charterers are to load and stow the cargo at their expense under the supervision of the Captain."*

The sales contract

15. Sinochem had sold the calcium hypochlorite to a company called Franmar Ltda, CIF Valparaiso under a contract dated 16th October 1998.

Arranging the carriage

16. On 5th November 1998 Sinochem applied to CSAV to have a cargo of calcium hypochlorite carried and delivered to San Antonio. CSAV agreed to carry the cargo provided that the documents were in order. On 10th November a Container Packing Certificate and Declaration on Safety and Fitness of Packaged Dangerous Goods were issued by a packing inspector for the container.

Bill of Lading

17. CSAV issued a bill of lading dated 30th December 2008 in respect of the container, numbered TTNU2959970, acknowledging the shipment of one container said to contain Calcium Hypochlorite 65%. The bill contains the following:

> *"IMO: 5.1. UN: 1748 PG: 5137"*

The reference is to paragraph 5.1.of the UN IMDG Code. One of the proper shipping names prescribed by the Code is "*Calcium Hypochlorite Dry"*, which has UN No 1748, which is at page 5137: see paragraph 49 below. The calcium hypochlorite (CH) was in granular form – described in the sale documentation as "*granular grande*".

18. The bill of lading incorporated the Hague Rules.

The manufacturer

19. UN 1748 is manufactured by reacting calcium hydroxide (lime) with chlorine gas in the presence of moisture. The water is then driven off by heat. It is not a pure chemical but comprises a range of solid compounds. Its main active constituent is calcium hypochlorite. The product is used, in solution in water, in bleaching processes and for water treatment.

20. The material shipped was, as is now known, manufactured by the Jingang Chemical Factory in Tianjin in around October1998. At that time the temperature in Tianjin would on average have been of the order of 20ºC or less. The material was put into kegs and the kegs were then put into a container. It is unclear whether the kegs were stuffed into the container at the factory (as was the evidence of Mr Wang Fei) or whether they were despatched from the factory by lorry and then loaded into the container at Xingang, Tianjin (see para 226 below). That was the port from which the container was taken to Busan, where it was loaded on the "Aconcagua".

The contents of the container

21. The container shipped by Sinochem was a standard 20 foot container with corrugated steel sides and top. It was fitted with a wooden or ply board floor approximately 30 mm thick. It contained 334 kegs of 45kg size, although one of them was not fully filled and contained only 15kg of cargo. The total weight of the contents was 15 tonnes. The kegs were plastic drums, known as quadritainers, and were lined with polyethylene bags. The quadritainers rested on the floor, and then on top of each other. There is no evidence of any wooden pallets being used in the stow. The precise arrangement of the stow is unknown. I consider the shape and configuration of the quadritainers in more detail in paragraph 303.

22. The container was carried from Xingang on the feeder vessel "Blue Star" which arrived at Busan from Yokahama at 2400 on 26th November 1998. During the voyage the ambient temperature was of the order of 5 – 10ºC.

Loading

23. Loading on the "Aconcagua" took place at Busan between 26th and 28th November 1998.

The layout of the vessel.

24. Holds Nos. 1 and 3 were approved for the carriage of dangerous goods of all classes, including explosives, since they were fitted with sprinkler pipe work in the hatch covers. Bay numbers used for stowing 20' containers were odd numbers. Those used for stowing 40' containers were even numbers. No. 3 hold contained four 20' bays numbered (forward to aft) 13, 15, 17 and 19. If 40' containers were stowed the bays were numbered (forward to aft) 14 and 18 (there was no 16). Thus, leaving aside some spaces at the side which would

only accommodate a 20’ container, No 3 hold might contain either two sets of 40’containers in Bays 14 and 18 or four sets of 20’ containers in Bays 13,15,17 and 19, or permutations of 20’ and 40’ containers as between the two parts of the hold. Within the hold containers would be stacked in tiers up to six high, numbered from the tank top 02, 04, 06, 08, 10 and 12. The rows of containers were numbered 12, 10, 08, 06, 04, 02, 01, 03, 05, 07, 09 and 11, with even numbers referring to the port side of the centre line and odd numbers to the starboard.

25. No. 3 hold was fitted with four natural ventilators, two forward and two aft, together with four mechanical exhaust ventilators located between the forward and aft hatches. In addition, there were four wall vents, two located in the forward hatch coaming and two in the aft coaming. The wall vents were simply covers and were not used.

26. The container was loaded in position 15-09-06, meaning Bay 15, Row 09, Tier 06, i.e. at the third level from the bottom at the furthest row starboard in the aft end of the forward section of No 3 hold. The position is illustrated in 3D in Dr Beeley’s figure 3 in Appendix 1. It also appears diagrammatically in the figure in that Appendix.

27. As can be seen the container sat on a “step” or “shelf” in the starboard side hold wall in front of the transverse partial bulkhead between the forward and aft sections of the hold. In front of it was the aft wall of part of No 3 FFOTS. To its starboard was the inboard wall of that fuel tank. Beneath it at level 04 was the roof of the oil tank below. It was, thus, bounded on all sides by No 3 FFOTS. The container was not in direct contact with the tank surface but rested by its “shoes” on “pads” welded to the tank tops. There was a gap of about 185-187 mm between the forward end and outboard side of the container and the facing sides of the tank.

28. No 3 FFOTS and No 3 AFOTS each had a capacity of 415.9m³ at 95% full and held about 407 m.t. of fuel oil at SG 0.98.

Bunkering

29. On or about 27th November 1998 the vessel took on 1,700 mts of bunkers at Busan. These were loaded into a number of the vessel’s bunker storage tanks including No 3 FFOTS. The recommended transfer temperature was 35ºC.

The voyage

30. On 30th November 2008 the vessel departed Busan for Keelung where she arrived on 2nd December 1998. She left the same day on completion of cargo operations and arrived at Hong Kong on 4th December, whence she departed on 6th December for the trans-Pacific voyage to Los Angeles. The vessel’s natural ventilators were opened on sailing Hong Kong but they were closed on 8th December because severe weather was forecast. They were then opened again a couple of days before the vessel arrived at Los Angeles on 20th December. The mechanical ventilators were opened at the same time but were

not run. On 19th December the fans were run for a few hours in the 0400 – 0800 watch. On the voyage to Los Angeles consumption took place from No 2 FOT (P & S), No 3 AFOT (P & S) and No 4 FOT (P & S.).

Los Angeles

31. On 20th December the vessel arrived at Los Angeles. Prior to then the sea temperature had been about 15ºC, and the temperature of the bulk of the oil in No 3 FFOTS would have been of that order.

32. No 3 hold was opened for cargo operations. The vessel took on 1,200 m.t of bunkers into:

(i) No 2 FOT (S);

(ii) No 3 AFOT (P & S);

iii) No 4 FOT (P & S).

The temperature of the bunkers was 48ºC. The vessel left Los Angeles at about 1700. No 2 FT (P) 2 then remained under consumption until 22nd December when consumption switched to Nos 3 FFOT (P & S). From about 22nd December onwards there was a marked increase in air and sea water temperatures as the vessel proceeded towards the Equator and into tropical waters. The vessel arrived at Manzanillo on 23rd December, when No 3 hold was again opened, and left for Balbao the next day.

Heating bunkers in No 3 FFOT (S).

33. At some time between 20th and 23rd December 1998 the vessel began to heat the bunkers in No 3 FFOTS by use of the heating coils at the base of the tank. I consider in paras 234ff below when precisely that was. It must have been before 0900 on 23rd December 1998 when fuel was first drawn from that tank. The practice of the vessel was to refill the settling tanks from the bunker tanks to between 72-75m³ (just below the high level alarm set at 75m³) and to do so when the level fell to about 35m³, so that the amount transferred would be about 35m³. The average daily consumption was about 70-80 tonnes. As a result bunkers were drawn from the No 3 FFOT (P & S) during the 0800 – 1200 and 1600 – 2000 watches.

34. The fuel oil in No 3 FFOT (S), when full extends into level 08. As it is consumed the level falls. On 25th December the level in the tank fell below the level of the top of the container. On 27th December the vessel arrived in Balboa which it left on 28th. On that day the level of the oil fell below the level of the bottom of the container. The effect of that was that any heating of the container and its contents had to be by the oil in the tank heating the air in the ullage space within the tank, and thus heating the tank wall, the air between the tank wall and the container, and the container itself.

35. On 30th December 1998 at about 02.30 LT the cargo in the container exploded whilst the vessel was on passage off Guyaquil, Ecuador. The hatch covers of No 3 hold were displaced. A huge fire developed in No 3 hold and spread vigorously. At 0340 the crew abandoned ship. Fortunately, and somewhat miraculously, no one was either killed or injured, despite the Chief Engineer having to jump from the main deck into the sea. The crew were picked up at about 0630 by another vessel the "Trave Trader". On 31st December 1998 the Chief Engineer and some other crew members returned to the vessel. On 21st January 1999 the vessel arrived at Balboa for removal of the debris and for repairs. On 16th April 1999 she sailed to Okpo where permanent repairs were carried out. She departed from Okpo shipyard on 29th June 1999, now renamed "CSAV Shanghai", under a new charter with CSAV.

The arbitration

36. In January 1999 the Owners commenced their arbitration. On 1st March 2005 the arbitrators (Christopher Fyans, George Henderson and Patrick O'Donovan) issued a declaratory award.

37. In summary they found, inter alia, the following:

(i) It was an implied term of the charter that CSAV would indemnify the Owners against the consequences of complying with CSAV's orders (paras 14 (1) and 126 (1) of the Reasons) and that the indemnity was not qualified in any of the ways alleged by CSAV (paras 14 (2) and 126 (2));

(ii) Stowage of the container in slot 15-09-06 was in breach of the IMDG Code and constituted a breach by CSAV of both clause 8 and clause 30 of the charterparty (paras 82 and 92);

(iii) The Chief Engineer was neither negligent nor unreasonable in the practices which he adopted with regard to bunker heating (paragraph 111) and in any event bunker heating constituted an "*act in the management of the vessel*" within the meaning of Article IV, Rule 2(a) of the Hague Rules (para 125).

38. The Owners continued to advance their claim and rebut the CSAV's counterclaim on other bases including the dangerous goods provisions of Article IV Rule 6 of the Hague Rules/USCOGSA and/or an implied term that the charterers would not ship goods of a dangerous character of which the shipowners could not be aware.

39. CSAV appealed to this Court under s. 69 of the Arbitration Act 1996. On 14th March 2006 Morison J dismissed the appeal: [2006] 2 Lloyd's Rep 66. He held that the question was not whether the Owners were under a duty to intervene in the loading process, but rather whether they owed that duty to CSAV. The reservation of the right of the Captain to supervise did not relieve the Charterers of their primary duty to stow safely, *Canadian Transport Ltd v Court Line Ltd* [1940] AC 934 and *Transocean Liners Reederei GmbH v*

Euxine Shipping Co Ltd (The Imvros) [1999] 1 Lloyd's Rep 848 applied, *The Panaghia Tinnou* [1986] 2 Lloyd's Rep 586 considered. The question as to the applicability of Art. IV Rule 2(a) was quintessentially one of fact for the arbitrators. They had set out the correct legal test and had applied it. The challenge to their decision that heating the bunker tanks was part of the running of the ship not related to the cargo was hopeless.

The settlement

40. On 25th April 2008 CSAV settled the Owners' claim. At that stage the claim was for US $ 29,000,000, together with interest in the sum of $ 17,000,000 and costs in the sum of £ 3,750,000. The settlement was in the sum of $ 27,500,000 inclusive of interest and costs It was a term of the settlement that, after payment, Owners should notify Dr Beeley and Professor Gray that they had no objection to their accepting instructions from CSAV in relation to CSAV's claims against shippers or manufacturers.

Calcium hypochlorite

41. It is common ground between the parties that calcium hypochlorite (CH) in whatever form it is produced is a dangerous cargo. CH has a well-known tendency to decompose spontaneously at certain temperatures. It does not require oxygen from the air in order to undergo this self-heating reaction nor is the rate of reaction limited by the availability of external oxygen. The reaction releases both heat and oxygen[3].

42. CH is susceptible at certain temperatures to a process by which the more heat that is produced within the material the hotter it gets and the more rapidly further heat is produced. The end result is known as "thermal runaway", which is characterised by the onset of a rapid marked temperature rise which may occur after a very prolonged period of gentle self heating of a few degrees. Rapid exothermic decomposition leads to the expulsion into the surroundings of very hot products of reaction. Surrounding materials are heated in an oxygen enriched atmosphere as a result of which ignition of nearby materials is made easier and burning rates increase by a very significant amount. Unquenchable fires may develop. UN 1748 CH can undergo vigorous decomposition if oxidised by certain materials such as a few drops of glycerine or another readily oxidised oil or grease (of which sun tan oil and hair grease are examples).

43. Whether or not the runaway process leading to self ignition occurs is dependent, inter alia, on the extent to which the heat produced is conducted away from the reacting material to its surroundings. If the rate of heat loss is large enough the temperature of the material will not rise sufficiently and only sub-critical self heating will occur. This may involve degradation of the material and the loss of some of its "available chlorine" but neither fire nor explosion.

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[3] According to a reaction pathway which produces calcium chloride and gaseous oxygen and is exothermic. $Ca(OCl)_2 \rightarrow CaCl_2 + O_2$. Exothermic decomposition can also be initiated by a source of ignition such as a match or a cigarette.

44. A number of factors are now known to influence whether or not decomposition leading to self ignition will occur. These include:

    (i) *The ambient temperature* i.e. the temperature of the immediate surroundings. The higher this is, the more difficult it is for the material to lose heat as it decomposes (since heat can only flow from a higher to a lower temperature). If heat cannot be lost then the temperature of the material itself increases and the decomposition reaction accelerates. It follows that when CH is subjected to heat, its susceptibility to ignition inevitably increases.

    (ii) *The water content of the mass*. The greater the water content, the greater, all other thing being equal, the susceptibility of CH to thermal instability. That does not mean that there is always a direct linear relationship between water content and thermal stability. The extent of increased thermal instability may depend on whether other catalysts such as metal ions are present, whether the water is present as water of hydration, and other factors.

    (iii) *The quantity of the material grouped together in a single unit or package*. The larger the size of the body the more difficult it is for the internally generated heat to reach the outside and the greater the rate of decomposition. The shape of the body in question is also relevant. The critical factor is the smallest dimension, which will provide the shortest path for heat loss. A sphere (which has no smallest dimension) gives the smallest heat loss for a given volume, whereas a long thin cylinder of equal volume and containing the same amount of material will lose heat more readily.

45. The rate of heat loss for a given quantity of material with a given water content at a given ambient temperature is not fixed or dependable. This is the result of a number of further factors:

    (i) CH is not produced as a pure chemical. A commercial cargo shipped as CH will not, therefore, consist exclusively of pure $Ca(OCl)_2$ but will also contain other materials. The precise make-up will depend on the process of manufacture and the nature of the raw materials used.

    (ii) The rate at which heat can be dissipated by a given quantity of material will also be affected by the geometry/surface area of that quantity of material: see para 44 (iii) above. Where it is in a package, it will be affected by the packaging material. Where it is one of several individual packages within a shipping container, it will further be affected by the relationship between the package and all the others, by the way that the heat generated by all of the package spreads within and through the shipping container and by the ability of the shipping container itself to lose heat to the wider environment surrounding it.

The International Maritime Dangerous Goods (IMDG) Code

46. Chapter VII of the International Convention for the Safety of Life at Sea 1974 (SOLAS) contains in Part A mandatory regulations governing the carriage of dangerous goods in packaged form or in solid form in bulk. Regulation 1.3 prohibits the carriage of such goods except in accordance with the provisions of Part A.

47. The IMDG Code contains information which is "*primarily directed at the mariner*" (para 4.1) although "*manufacturers, packers and shippers should be guided by the advice given for terminology, packing and labelling*" (para 4.2.). The Code specifies a number of proper shipping names (PSN) which are also the "*correct technical names*" referred to in Regulation 4.1 the purpose of which is to ensure that the substance, material or article can be readily identified during transport (para 7.1.2.).

Class 5.1

48. Regulation 2 provides for dangerous good to be divided into 9 classes of which Class 5.1 is "*Oxidising Substances*". "*Oxidising substances*" are defined as "*Substances which, while in themselves not necessarily combustible, may, generally by yielding oxygen, cause, or contribute to, the combustion of other material*". Paragraph 1 of Class 5.1. provides:

> *"1.1 Substances of class 5.1 in certain circumstances directly or indirectly evolve oxygen. For this reason oxidising substances increase the risk and intensity of fire in combustible material with which they come into contact."*

UN 1748

49. The Schedules for Class 5.1 provide for three categories of calcium hypochlorite which may be relevant. The first, on page 5137, is UN 1748, the category declared by Sinochem to CSAV. That category specified the following material:

> *CALCIUM HYPOCHLORITE, DRY or CALCIUM HYPOHCLORITE MIXTURE, DRY with more than 39% available chlorine (8.8% available oxygen). UN No 1748 Formula:* $Ca(Ocl)_2$ *"*

Under the heading "*Properties*" there was included the following:

> *"Critical ambient temperature of decomposition may be as low as 60ºC"*[4]

Under stowage the following was specified:

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[4] This warning was introduced in 1981. The likelihood is that it represents the view of the UK delegation as to the lower bound for anhydrous CH. It was removed in 2002. In its place there was substituted a warning that it was a substance liable to exothermic decomposition at elevated temperatures.

> *"Category D*
>
> *Category E, freight containers and pallet boxes only*
>
> *Ventilation may be required. The possible need to open hatches in case of fire to provide maximum ventilation and to apply water in an emergency, and the consequent risk to the stability of the ship through flooding of the cargo space, should be considered before loading. "*
>
> *"Separated from" powdered metals, ammonium compounds, cyanides and hydrogen peroxide*
>
> *"Away from" sources of heat"*

Stowage category D is, for cargo ships, "*On Deck Only*" (3.1.4). Stowage Category E is, for cargo ships, "*On Deck or Under Deck*" (3.1.5).

UN 2880

50. UN 2880 specifies the following material:

> *"CALCIUM HYPOCHLORITE, HYDRATED, or CALCIUM HYPOCHLORITE, HYDRATED MIXTURE with not less than 5.5% but not more than 10% water.*
>
> *UN No 2208* *Formula:* $Ca(OCl)_2. H_2O$*"*

UN 2208

51. UN 2208 specifies the following material, which is commonly known as "bleaching powder":

> "*CALCIUM HYPOCHLORITE MIXTURE, DRY with more than 10% but not more than 39% available chlorine."*

52. UN 2880 was introduced in 1981. There is an issue between the parties as to whether it was open to Sinochem to declare the cargo as UN 1748 if it had a moisture content in excess of 1%. CSAV contends that UN 1748 describes calcium hypochlorite, dry, sometimes referred to as "anhydrous"; that its maximum moisture content is 1%; and that the calcium hypochlorite on the "Aconcagua" was not UN 1748. Sinochem contends that, even if the cargo had a moisture content in excess of 1% (but not exceeding 5.5% - see UN 2880) it was properly declarable as UN1748.

The essence of the claim under Article IV, rule 6

53. CSAV claims that Sinochem is liable to compensate it for the damage it has suffered under Article IV, Rule 6 of the Hague Rules, which provides:

> "*Goods of an inflammable, explosive or dangerous nature to the shipment whereof the carrier, master or agent of the carrier has not consented with knowledge of their nature and character, may at any time before discharge be landed at any place or destroyed or rendered innocuous by the carrier without compensation and the shipper of such goods shall be liable for all damages and expenses directly or indirectly arising out of or resulting from such shipment*".

There is also a pleaded claim to recover on the basis of an implied undertaking; but it is not suggested that CSAV has any better right to recover under that heading. In view of the provisions of Article IV, rule 6 it is doubtful whether any implied indemnity is applicable.

54. In *Mediterranean Freight Services v BP Oil (The "Fiona")* [1993] 1 Ll. Rep. 257 at 268 Judge Diamond, QC, identified what a carrier has to prove in order to recover:

> *"In my view it is clear as a matter of construction that if the carrier is able to prove the three matters specified in art. IV, r. 6 then he is entitled to recover compensation from the shipper for the loss sustained by him as the result of the shipment of a dangerous cargo. What the carrier has to prove is (a) that the shipper shipped goods of an "inflammable, explosive or dangerous nature"; (b) that neither the carrier, the master nor any agent of the carrier consented to the shipment of such goods with knowledge of their nature and character and (c) that the carrier suffered damages or expenses "directly or indirectly arising out of or resulting from such shipment" (i.e. from the shipment of the goods of the described class)."*

55. As Judge Diamond also observed, the carrier's right to an indemnity does not depend on whether the shipper knew of the dangerous nature and character of the goods or was at fault in permitting their shipment or not warning the carrier of their dangerous nature.

Distribution of risk

56. The Hague Rules provide, by specifying a series of obligations, liabilities and exceptions, a scheme for the apportionment of the risks inherent in the carriage of goods by sea, including, in particular, the risk of a dangerous situation arising on the voyage: see *The "Athanasia Comninos"* [1990] 1 Lloyd's 277 at 282. Article IV, Rule 6 is one of the provisions giving effect to that apportionment. Whether or not it can be invoked is not dependent on asking whether UN 1748 was known to be dangerous and one of the risks of its carriage was self-ignition, and, in the light of the affirmative answer to be given to those questions, deciding that the claim must fail. The essential question, as Mustill, J (as he then was) pointed out, is whether on the true construction of the bill of lading contract the risks involved in the shipment of what was said to be UN 1748 were risks which CSAV contracted to bear. CSAV must be taken to have agreed to bear all the risks inherent in the carriage of UN 1748 of which it had knowledge. For this purpose knowledge is not limited to actual knowledge. The standard of knowledge on the part of

the carrier is *"that of the ordinarily experienced and skilful carrier of goods of the general kind shipped"* (Cooke, *Voyage Charters*, para 85.431). For brevity I refer to him hereafter as a "prudent carrier".

57. In *The "Athanasia Comninos*" Mustill J said that in many cases the question whether or not goods were dangerous might be resolved by asking whether or not the carrier had performed the contract of carriage in a manner appropriate to their particular description. If he had, and the danger materialised, the cargo might be regarded as abnormal since in respect of the great majority of goods "normal" precautions would eliminate the risk of carrying normal goods; so that proper carriage and dangerous goods were opposite sides of the same coin. He pointed out, however, that there were cases where so simple an analysis could not be applied. Some risks might materialise despite an acceptable standard of care of the cargo but in circumstances in which the cargo possessed the normal attributes of the goods described, including the capacity to create dangers which the accepted methods of carriage could not always overcome. In such a "bad luck" situation the carrier would be responsible. Per contra the shipper would be liable if the risks inherent in the cargo shipped were of "*a totally different kind (whether in nature or degree)*" from those attached to the carriage of the described cargo.

58. Mr Robert Bright, QC, for Sinochem, observed that in the present case CSAV accepts that stowage of the container in 15-09-06 was negligent; and that Mustill, J did not envisage circumstances in which a carrier might succeed despite his failure to perform the carriage in a manner appropriate to the goods in question. It was accordingly necessary for CSAV to show not merely that UN 1748 presented risks of a totally different kind; but also that the sole cause of the explosion was the "rogue" nature of the cargo. I do not, however, regard Mustill J's observation that in many cases proper carriage and "dangerous nature" are opposite sides of the same coin as necessarily excluding the possibility that the abnormal nature of the cargo and inappropriate care might be concurrent causes of the casualty; or to have decided where, in that event, liability would lie.

The issues

59. The issues raised by CSAV's claim include, therefore, the following:

(a) What characteristics should a prudent carrier have expected of goods declared as UN 1748?

(b) Did the CH actually shipped have such characteristics or did it have abnormal characteristics which rendered it more dangerous than was to be anticipated?

(c) Was the explosion and resultant damage the result of such abnormal characteristics; or of the stowage of the container on top of a bunker tank that was heated, or both? and

(d) what is the legal consequence if bunker heating was either *the* or *a* cause of the CH igniting?

The characteristics of UN 1748

60. The dangerous quality of CH is not a new phenomenon. In *Brass v Maitland* (1856) 6 E & B 470 Lord Campbell held that there was an implied undertaking on the part of the shippers of goods on board a general ship that they will not deliver to be carried on the voyage packages of a dangerous nature which those employed on behalf of the shipowner may not on inspection reasonably be expected to know to be of a dangerous nature without giving notice. The cargo in question was chloride of lime (bleaching powder) which was loaded in London on a vessel bound for Calcutta. During the voyage the bleaching powder corroded and burst the casks and destroyed various goods on the ship. The exact nature of the cargo is unknown but it may well have been what is now classified as UN 2208.

61. In seeking to determine the "*nature and character*" of UN 1748, as that was or ought to have been known to CSAV in 1998, it is necessary to take into account :

(i) the hazard history of UN 1748;

(ii) the significance of the description of UN 1748 in the Code, whose provisions ought to be known by a prudent carrier; and

(iii) any other information of which the prudent carrier ought to have been aware.

62. A prudent carrier is not required to have the knowledge of an expert chemist or to "*resort to investigation inconsistent with the usual course of business"*: per Lord Campbell in *Brass v Maitland*; Pearson J in *The "Atlantic Duchess*" [1957] 2 Ll. Rep 55, 96; *Heath Steele Mines Ltd v The Erwin Schroder* [1969] 1 Lloyd's Rep 370; and The *Athanasia Comninos.* He is likely to have less knowledge about a product than a specialist manufacturer or distributor, although the owners of vessels specially constructed for the purpose of carrying particular cargoes (e.g. LPG) may have particular specialist knowledge.

63. A prudent carrier would encounter considerable difficulty in finding, and perhaps of understanding, some of the academic work that has been put before me. Such material may be informative as to the nature of CH. But it does not necessarily represent what the prudent carrier should have known about it. With that caveat in mind I shall, after considering the hazard history, address some of the academic work on the subject, not least because some of that work interrelates with the hazard history and forms part of the context in which the specification of UN 2880 was written, to the interpretation of which I shall then turn.

The hazard history

64. In a paper delivered to a symposium of the Institute of Chemical Engineers in 1987 Dr Vernon Clancey of Burgoyne Consultants Ltd observed that:

> *"Practical experience over many years and involving large quantities has shown that normally the packaged material may be safely stored even under the highest ambient temperatures usually experienced. On the other hand there is firm evidence that complete unopened drums have spontaneously ignited. The frequency of these events is such that they must be considered to be rare and exceptional in some way"* page 16.
>
> *"Observed incidents of apparently spontaneous explosion and fire are rare events, and may therefore be ascribed to unusual or rogue drums, that is drums of which the contents are, for whatever reason, of lower stability or greater sensitivity than normal": page 19.*

65. The antecedent history, so far as marine carriage is concerned[5] may be summarised as follows:

    i. Dry calcium hypochlorite (with an available chlorine of 60-70% and a moisture content of up to about 1%) has been manufactured since the 1920s. The first manufacturer was the Mathieson Alkali Works, the forerunner of Olin and Arch. It has been shipped across the world by sea in considerable volumes ever since that time. Such carriage must have included volumes carried in tropical waters and hot climates effected on older style vessels such as tweendeckers where the effect of hold heating is very much more pronounced than on a containership.

    ii. There are no known incidents of it exploding at sea before the late 1960s.

    iii. Prior to the late 1960s dry calcium hypochlorite was manufactured exclusively in America with Olin being the most prominent manufacturer. In the late 1960s, Japanese manufactured material began to come onto the market and to be carried by sea.

    iv. Thereafter there was a spate of explosions on board ships attributable to the material undergoing thermal runaway and spontaneous combustion. Between 1967 and 1973 there were a dozen reports of fires and explosions, some in port (where the incident may have been similar to a domestic incident[6]) and some at sea. They are listed by Dr Clancey in an article of his written prior to November 26th 1974 and printed in the *Journal of Hazardous Materials* in 1975. Two of these incidents involved fatalities. As that article recorded:

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[5] As opposed to the problem of explosions in a domestic context e.g. by the introduction of organic material into an open container of the material.

[6] E.g. a stevedore putting a cigarette into a burst can.

> "*It was apparent from the accidents that the greatest risk was with material of Japanese origin. The product of the major U.S. manufacturers appeared to be relatively trouble-free*": page 91.

v. These incidents led to a P & I club circular being issued on 31st July 1974 warning carriers of the dangers of carrying calcium hypochlorite and recommending that cargoes of the material be carried only on deck.

vi. The casualties and their cause were investigated on behalf of the London Group of P & I clubs during 1974 and 1975 by a joint team of experts from the then major firms (Messrs Clancey, Byrne, Donegan and Milton) who carried out research at the Royal Armament Research and Development Establishment, Woolwich. They reported in May 1975 ("the joint report"). The joint report was not published.

vii. Initially four samples were available; each of three drums, said to be from (a) Olin; (b) Nippon Soda; (c) Nankai; and (d) an unnamed German manufacturer. Subsequently a further 12 samples, said by the manufacturers to be taken at random from normal production, were received (3 each) from 4 Japanese manufacturers (a) Nippon Soda (Nisson – 60% hypochlorite); (b) Nippon Soda (Hichlor 70% hypochlorite); (c) Nankai and (d) Nissin. Of these the Nippon Soda material had become very consistent and similar to the original Olin material, suggesting production under more controlled conditions. The other two products showed a wide range of results indicative of less control during manufacture.

viii. The investigation's conclusions included the following. Calcium hypochlorite with high available chlorine decomposes giving out great heat and yielding large quantities of oxygen and some chlorine but this did not apply to ordinary bleaching powder with 39% available chlorine or less (para 4). The composition of the Japanese products was variable from drum to drum indicating *a lack of rigid control* during manufacture (para 18). When the dry material was heated there was a great and significant difference in the behaviour of the Japanese products as compared with the Olin and German products. After being held at a constant temperature for a short time the Japanese product began suddenly to decompose at a very rapid and accelerating rate compared with the slow and steady rate of decomposition of the other products (para 29). This difference showed that from a hazard point of view the two types of product were to be regarded as in different categories. The temperature from which runaway decomposition occurred with the Olin material was about 100-110ºC and with the Japanese material about 70-80ºC (paras 32 and 33). The variation in composition found between Japanese drums made it probable that *rogue drums* could occur in a batch which would undergo spontaneous decomposition at lower temperatures (para 35). During production unstable by-products might be present as a result of variations in production conditions or impurities might be introduced; during or after packing foreign matter might be present. If this occurred either as a result of lack of efficient control of raw materials and manufacturing processes or by the use of dirty or contaminated drums or by permitting the fortuitous entry of "dirt" it was possible to get "rogue" drums capable of spontaneous ignition from ordinary ambient temperatures. The evidence suggested a greater variability in the Japanese product than Olin's which would suggest a greater possibility of the occurrence of such "rogue" drums (page 34).

ix. Dr Clancey's conclusions are also expressed in his 1987 paper: see paragraph 64 above.

x. Following the investigation, representations were made to the International Maritime Organisation ("IMO") by the UK and Dutch delegations seeking to amend the UN1748 entry to provide for *deck carriage* only of such cargo. This was countered by the US and other delegations.

xi. The IMO concluded that there was no justification for limiting carriage to on-deck only and, in effect, reversed the earlier P & I Club recommendation. Carriage of UN1748 was thereby pronounced to the marine community to be a cargo which could safely be carried in containers whether on or under deck.

xii. There were no further incidents of explosion of dry calcium hypochlorite at sea after the spate of incidents involving rogue Japanese material which ended in 1973 (save for an incident on the mv "Recife" in 1991: see (xvi) below). As Mr Charlton accepted [7/124] dry CH UN 1748 had an exceptionally good marine carriage track record prior to and since those incidents.

xiii. By the early 1980s there was a skewing of world production towards the hydrated product, UN 2880; and the anhydrous product stopped being produced by developed as opposed to developing countries. That product, although it may have certain advantages from a safety point of view has a much lower tolerance to ambient temperatures than anhydrous. Even so there seem to have been no reported incidents involving UN 2880 until those referred to at (xvi) below.

xiv. Two reasons were perceived as an explanation for the reduction in incidents in relation to the anhydrous product: first the increasing palletisation and containerisation of cargoes reduced the spillage or domestic type incident, and secondly, perhaps, a tightening by the manufacturers (sc. the Japanese manufacturers) of their production process: see para 2.1 of a paper of Professor Gray, Dr Holleyhead and Mr (as he then was) Halliburton, annexed to a paper before the DGSC dated 5th November 1999, entitled "*A study of the thermal properties of Hydrated Calcium hypochlorite (UN 2880)*" annexed to a paper submitted to the Dangerous Goods Sub-Committee ("DGSC") of the IMO by the International Groups of P & I Clubs proposing amendments to the IMDG Code.

xv. Between 1974 and 1998, when the explosion on the "Aconcagua" took place, there was only *one* reported incident of an explosion at sea involving

UN1748. This involved the "RECIFE" in 1991. In that case the competing causes were a rogue product with impaired thermal stability due to contamination of briquettes (sterilising tablets for swimming pools), which was the thesis of Burgoynes (Dr Atherton), as against insolation of the container stowed on deck in a voyage in high summer from Africa to the US Gulf at the top of the stow. There was a trial in which the judge accepted Burgoyne' thesis; but he was overruled on appeal.

xvi. The other casualties, many but not all of which took place in tropical latitudes, were as follows:

VESSEL	**DATE**	**UN No**	**ORIGIN**
MV RECIFE	1991	**1748 Anhydrous**	SOUTH AFRICA
TIGER WAVE	1997	2208 Bleaching Powder[7]	INDIA
MAAS	1997	?	
CONTSHIP FRANCE	1997	*2880 Hydrated*	USA: **
MAERSK MOMBASA	1998	2208 Bleaching Powder	EGYPT
SEA EXPRESS	1998	2208 Bleaching Powder	CHINA
DG HARMONY*	1998	*2880 Hydrated*	USA: **
ACONCAGUA	**1998**	**1748 Anhydrous**	**CHINA**
CMA DJAKARTA	1999	2208 Bleaching Powder	CHINA

* Reported in Lloyd's List 11th November 1998.
** The manufacturer was PPG which had had a stability problem with the product because in 1995 it had switched quarries. In late 1998 it switched back. This longstanding problem was recorded in internal documents disclosed by PPG. In the case of the "*Contship France"* the product was in 400 lb drums. An English arbitration award accepted the thesis put forward by Burgoyne's on behalf of the owners that heating played no part in the casualty. A US Court, in a claim in which the Club appears to have played no part and in which this evidence presumably played no part, reached a contrary decision.

In the case of the *DG Harmony* a US Court held that the cargo blew up without being heated directly by a bunker tank (being separated from it by two containers).

xvii. In November 1999, i.e. after the casualty, in the aftermath of the "Contship France", Professor Gray, Dr Holleyhead and Mr Halliburton produced a study of the thermal properties of UN 2880 which was put before the

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[7] This low-strength product has had a history of explosions since the beginning of the last century.

DGSC when it considered amending the IMDG Code. In the course of this Professor Gray developed his interaction theory: see para 104 below.

The characteristics of UN 1748 apparent from its hazard history

66. In my judgment the understanding that a prudent carrier would have had in 1998 of UN 1748 from its hazard history was that the material was safe for carriage on or under deck; and that the cause of the explosions that had taken place with UN 1748 material up to 1973 was probably rogue Japanese product of abnormally low thermal stability attributable to a lack of proper care on the part of the manufacturer in quality control. The problems with CH experienced in the 1990s were, with one exception (where the cause was unclear) problems with UN 2880 or 2208, which had different characteristics; Whilst such a carrier could not be expected to have the full detail of the history summarised in the previous paragraphs he would, as it seems to me, have the understanding that I have mentioned, which is the tenor of what had been communicated to the Clubs and therefore carriers' interests.

The Critical Ambient Temperature

67. Before I turn to consider the academic work, it is necessary to discuss one particular parameter – the critical ambient temperature. For any given self-heating body there is an ambient temperature – the critical ambient temperature (CAT) - at or above which thermal runaway or ignition will occur and below which only sub-critical heating will occur (provided that the initial temperature of the body itself is equal to or below ambient).

68. The fact that the CAT is exceeded does not mean that the body of material in question will immediately ignite (although, if the ambient temperature remains above the CAT it will probably do so in time). The ambient temperature may, of course, cross and re-cross the CAT boundary. Whether the material blows up in those circumstances will depend, inter alia, on for how long and to what extent the material is subject to temperatures above its CAT. The larger the excess of ambient temperature above the CAT the shorter is the time necessary to cause the material to explode.

69. Whether ignition occurs is also influenced by the size of the body in question. Thus a short but very large temperature spike may have no appreciable effect on a very large body. In addition different bodies have different degrees of thermal inertia represented by the time which a body takes to respond to heat. Further details as to the nature of the CAT are set out in Part 1 of Appendix 2.

Calculating the Critical ambient temperature

70. It is possible to calculate the CAT for any given material by reference to its properties, including, in particular, its thermal conductivity. Work on determining the appropriate formula for calculating the CAT of a material was carried out by, inter alios, Messrs Semenov, Frank-Kamenetskii, and

Barzykin. The details, which are complex, may be found in Part 2 of Appendix 1.

The academic work and literature

The 1974 and 1975 papers

71. The 1974 paper by Dr Clancey referred to in paragraph 65 (iv) above was published when the research programme conducted at the request of the London P & I Clubs, following the 1967-1973 spate of incidents and led by him was in its early stages. That programme itself was the first modern research programme into CH.

72. One of the matters discussed in the paper was the variability of the commercial product. Mr Clancey concluded that: *"…the hazard status of commercial samples is different as between the products of different manufacturers. Further differences exist between the materials in different drums from the same maker and, perhaps, between material from different parts of the same drum."* This was in part because the product was *"not a single substance"*[8] and the raw materials used contained impurities which might vary between sources.

73. The 1974 paper noted that the important question was whether self-heating could occur from such temperatures as might exist in a ship's hold, a question which the research programme was intended to address. In this paper Dr Clancey concluded: *"So long as calcium hypochlorite of the present quality is shipped there will be a hazard."*

74. The results of the programme were reported to the Clubs in the joint report in May 1975: see para 65 (vi) above. The joint report was co-written by Dr Clancey and some of the other leading specialists of the day. A summary of the principal findings was given by Dr Clancey in the paper submitted by him to the 1987 symposium: see para 64 above. It is apparent from those two sources that self-heating tests carried out on the samples initially obtained and on the "new" samples (see para 65 (vii) above) included the following results:

Sample	**Lowest runaway temp °C**	**Time in hours**
A Olin, old	110	10
Nippon (Hichlor) (new)	**70**	15
B Nippon (Hichlor) (old)	100	5
Nankai (new)	**70**	10

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[8] There is present about 30% of inert substances which *"may vary as between different manufacturers and indeed vary from time to time in the output of a manufacturer."* In addition, diffraction patterns revealed unidentified components present in some samples and not in others: see page 86

C Nankai (old)	80	10
Nippon (Nisso) (new)	**80**	6
A Olin (old) + 3% water	70	16
A Olin, (old) + 6% water	70	15
Nankai (new) + 3% water	60	14
Nankai (new) + 6% water	60	14

The letters are the letters given to the samples in the 1987 paper.

75. The experiment involved heating 400g of the product in Dewar flasks (vacuum flasks designed to reduce heat losses) which were placed in an oven at various controlled temperatures. The objective of the test was to find the highest temperature at which the material would not run away and the lowest temperature at which it would do so, to the nearest 10ºC . This method means that the CAT could have been up to 9º lower than the figure recorded but not higher.

76. Sinochem draws attention to several features of these tests. Firstly, on the assumption that what the Japanese manufacturers produced was normal product, they confirmed a lower range of CAT for the spectrum of such "*normal*" material. The "new" samples of two different Japanese materials, produced by two different manufacturers, Nippon Soda (Hichlor) and Nankai, went into runaway at 70°C. Secondly, the tests showed that the addition of water had the effect of reducing the relevant temperature. The addition of 3% water reduced the runaway temperature of the new Nankai material from 70°C to 60°C. Thirdly, the tests showed that old material tends to be *less unstable* than new material. That was to be expected because old material will tend to be partially decomposed. Fourthly, the 1975 paper noted that it would be possible to carry out much more detailed thermal stability testing using Frank–Kamenetskii ("F-K") theory.

Uehara 1978

77. In 1978 Uehara and others in Japan carried out, for the first time, research to establish a CAT for UN 1748 material: see *Thermal Ignition of Calcium Hypochlorite (Uehara, Uematsu & Saito) Combustion and Flame 32, 85-94 (1978).* The material in question was Nippon Soda (Hichlor), but the results produced were different. They gave a CAT for a commercial package of 75°C to 77ºC - higher than the runaway temperature of 70ºC noted by Clancey for the same product in a 400g sample.

78. Some of Uehara's work required correction as Professor Gray expounded in his paper in 1999: *Study of the Thermal Properties of Hydrated Calcium Hypochlorite UN2880 (Gray, Holleyhead, Halliburton) DSC 5/3/6 (1999), Appendix "Comments on the paper of Uehara et al (1978)".* See also: *The Thermal Decomposition of Hydrated Calcium Hypochlorite UN2880, Gray & Halliburton, Fire Safety Journal 35 (2000) 223-239 at 237.* In his first report in these proceedings (Appendix 11) Professor Gray has recalculated the

Uehara data. The measured CATs for commercial size drums are in the region of 77ºC.

Bowes 1984

79. In 1984 Mr Bowes wrote a monograph on self-heating, which was published by the Department of the Environment. In relation to CH he used solely the data from the Uehara 1978 paper. On the basis of that data Bowes considered what might happen in the context of larger quantities on board ship, bearing in mind his own earlier research into the average temperatures likely to be experienced in the holds of ships. These appear to have been general cargo ships with lower holds and tween decks (which experience higher temperatures than modern container ships[9]).

80. He gave estimates for the quantity of Uehara-type material that would have CATs of 40°C, 50°C and 60°C, if arranged in cubes. He found that the necessary cubic dimensions would be 4.3m, 2.1m and 1.1m, respectively. He noted that there was:

> "*a possibility of self-heating and thermal explosion in "high strength" calcium hypochlorite in warm surroundings such as the upper holds of ships in tropical waters. However, the assignation of self heating as a cause in any given incident of fire and explosion must include a consideration of the possibility of differences in reactivity between samples of different manufacture and effects of contamination with impurities and water (Clancey 1975/6).*"

This appears to have been the first published warning of the possibility of explosion at 40°C. Sinochem observes that, if "*normal*" commercial CH could in principle include material that was appreciably less stable than the specific samples tested by Uehara – as shown by Clancey in 1975 – then the cubic quantity required for runaway at 40°C would be reduced accordingly. However, it is necessary to bear in mind that a cube of 4.3 metres is the equivalent of a solid block of CH weighing about 66.8 metric tons and that CAT reduces the larger the body.

Bibby & Milestone 1984

81. In 1984 Bibby & Milestone ("B & M")'s paper – *The Decomposition of High Grade Bleaching Powder (Calcium Hypochlorite)* was published in an academic journal. Their research was conducted on samples manufactured in Japan and the USA obtained from commercial outlets in New Zealand. The samples were either of 70% or 65% available chlorine levels. The authors found that the major component in the 70% material was anhydrous $Ca(OCl)_2$ (i.e.UN1748) while the major component in the 65% material was the trihydrate molecule $Ca(OCl)_2.3H_2O$. The tests conducted included isothermal

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[9] He appears to have concluded from data dating from the 1950s that a maximum average temperature for a period of a few days at sea in the hottest parts of the hold i.e. near deck and side plates on a voyage via the Caribbean and Panama would have been about 52ºC.

calorimetry. They found that heat output increased significantly above a temperature of about 50°C. When the relevant figure is examined[10], it can be seen that the pattern of increase in heat output varied between the two 70% samples tested (indicated respectively as X and O).

82. These results can be compared directly with the data set out by Prof. Gray in relation to heat output at 45°C, in table 16 of his first report. He expressed the view that the power production of a container load of "*normal*" UN1748 (by which he meant Donghai material – see para 161 below) was less than a 60 Watt light bulb – 57 Watts, whereas the power production of a container load of Jingang drum 12 (Jingang being the manufacturer of the CH shipped see para 161 below) would be 1,284 Watts. However, B & M's tests show that the power production of a container load of their sample X at 45°C would be 1,428 Watts.

83. I refer in paragraph 207 below to a heat output graph which shows a marked distinction between the results for Donghai, Zhenjiang, Sample A and Uehara material, on the one hand, and J-12, J-5, B & M and UN 2880 material on the other. Professor Gray suggested that the B & M material was, itself, abnormal because it was similar to UN 2880 which had exploded on board the "Contship France" and the "DG Harmony". It will be necessary to consider whether "normal" UN 1748 had characteristics which mean that it is liable to explode on ships such as the "Aconcagua" in voyages such as this; or whether it was abnormal UN 1748 to which the B & M material was similar (or which was worse than the B & M material) which caused explosion to happen. The 1984 paper was not concerned with the normality or otherwise of the material investigated. It noted, inter alia, the effect of heating rates on decomposition; of small amounts of metallic impurities on heat output; and the role of water in decomposition.

Clancey 1987

84. In 1987 Dr Clancey delivered his paper to the Institute of Chemistry Symposium: see paragraph 64 above. This summarised the results of the research done in 1974-1975. Dr Clancey applied heat transfer theory to calculate the CAT of the materials tested if the relevant quantity was equivalent to a commercial drum. The methodology is not set out in the 1987 paper itself, but has been found in Burgoyne's archives and was explained by Mr Phillips.[11] It is derived from the F-K definition of δ (See Appendix 2).

85. Dr Clancey calculated that the CAT for a commercial package would be approximately 20°C lower than that of a 400g sample; so that the CAT for a commercial package of new sample B – Nippon Soda (Hichlor) – or new sample C – Nankai – might be as low as 50°C[12]. That was the calculated CAT for a single drum. He observed that in the case of a close-packed stow of many

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[10] Figure 4(a) [J/4/428]

[11] Mr Phillips was not challenged on his explanation as to the validity of Mr Clancey's calculations. Professor Gray disagreed with Dr Clancy's method.

[12] There is no reason to believe that these new samples were abnormal.

drums in a ship's hold the dangerous ambient temperature would be considerably lower because of the restriction on heat loss. This was the beginning of an idea to which Professor Gray gave expression of the effect of the interaction between a number of drums in a container on the CAT.

86. He then observed:

> *"FULL SCALE DRUM TESTS*
>
> *Some doubts must arise regarding the validity of the extrapolation from small scale Dewar vessel experiments to 50 kg drums. Uehara et al carried out full scale tests with commercial drums and obtained a critical ambient temperature of 75ºC of 38cm diameter, that is 50kg. This compares very well with the values we obtained for sample B* [i.e. Nippon (Hichlor)] *old which was made by the same manufacturer. Our figure of 100ºC in the Dewar vessel reduces to about 80ºC for a full size drum. But the same maker's new sample (B new) gave 70ºC in the Dewar vessel which reduces to about 50ºC for a full size drum".*

Discussion

87. In the light of this material Sinochem submits that in 1998 "the trade" would have known that CATs as low as 40ºC could be expected in containerised assemblies of packages of UN 1748.

The prudent carrier's knowledge of the academic work and of CATs as low as 40ºC

88. The relevant question for present purposes is what was or should have been the knowledge of a prudent carrier, rather than that of a manufacturer, shipper or distributor. I am not persuaded that at the time of the loading of the "Aconcagua" in 1998 a prudent carrier in CSAV's position would or should have known that CATs as low as 40ºC could be expected if CH was carried in large numbers of packages in containers.

89. In the first place, I recall the description of UN 1748 in 1998 (and earlier) included (see para 49) the following:

> *"Critical ambient temperature of decomposition may be as low as 60ºC"*

A prudent carrier would reasonably take that as signifying that the CAT could go down as low as 60ºC but not further. Such information would tally with the hazard history of which he would be aware.

90. Mr Bright submitted that a carrier would not be likely to know what the CAT signified; that he would, therefore, have to ask someone, and that the person he asked would tell him that CAT depends on package size; and that it was impossible to tell to what package size this description related. I do not accept this. It seems to me that a prudent carrier would properly treat this description as representing the lowest temperature at which decomposition would begin as

60º, even if the material was stored in containers - as UN 1748 contemplated that it might by specifying "*Category E, Freight container and pallet boxes only*". This material generally is carried in containers.

91. A prudent carrier would not have been likely to have been aware, nor should he have been aware, of what Mr Bowes' 1984 monograph said about CH. Nor do I accept that Mr Bowes' hypothetical calculation, based on the F-K self heating equation, of a CAT for nearly 67 tons of product should be regarded as indicative of the CAT which a prudent carrier ought to have anticipated for the container and its contents.

92. Nor can a prudent carrier be expected to have been aware of Dr Clancey's 1987 paper delivered to a symposium of the Institute of Chemical Engineers, and not further published nor its contents disseminated, nor of the work done by Clancey in 1974/5, reported in the 1987 paper, whereby he derived from a single Dewar flask test of 400g of material a 50ºC CAT for a drum. The details of that are most fully set out in the joint report which was also never published. Nor would the prudent carrier have been aware of Dr Clancey's 1974 article (see para 65 (iv) published in the Journal of Hazardous Materials in 1975.

93. Three further matters are to be noted. Firstly, extrapolation from Dewar flaks is not reliable. Professor Gray expressed the view that using a 400 gram Dewar flask was "*a pretty hopeless test*" and certainly not the best way to do it. He and Dr Halliburton had abandoned the use of a smaller Dewar vessel instead of a 193 kilogram drum when investigating the "Contship France". I regard this assessment as sound. To use a single reading in respect of a 400g sample to predict the CAT of a body of 45+ kilos is fraught with difficulty.

94. Secondly, immediately after the passage referred to at para 85 and before that set out at para 86 ("*Some doubts*…."). Dr Clancey made the following observations:

> *"Very little is known about the effect of close packing of a large number of drums or of the diurnal variations of temperatures in a stowage.*
>
> *If the close packed drums could be treated as a solid cube, thermal theory could be applied…"*

A prudent carrier could not be expected to have greater knowledge than the scientists about the effect of close packing. Dr Clancey then went on to point out that Bowes' figure of 40ºC for a 4.3m diameter cube would have an ambient temperature higher by an indeterminate amount if there were air spaces between cylindrical drums. Further, the exercise of treating close packed drums as if they were a solid cube with no air space and deriving a CAT for that from a 400 g sample was of limited practical utility if, as was the case in the container on the "Aconcagua", the solid cube hypothesis was defective (as I think it was: see para 313 below).

95. Thirdly, a prudent carrier, who happened to read the Clancey paper would necessarily have observed the conclusion on page 19, cited in para 64 above, that:

> *"Observed incidents of apparently spontaneous explosion and fire are rare events, and may therefore be ascribed to unusual or rogue drums, that is drums of which the contents are, for whatever reason, of lower stability or greater sensitivity than normal."*

Sinochem's submissions on the known characteristics of CH

96. Sinochem submits that in 1998 UN 1748 CH had a number of known characteristics of which the following is a summary. It had a *propensity to decompose* and release energy causing self heating which could develop into thermal runaway. That tendency could be exacerbated by a number of factors of which the most significant was *water content*. Generally speaking the greater the water content the less stable the material; although the extent of the influence of moisture content may depend on whether the water is present as water of hydration, and what other catalysts such as metal ions are present[13]. Other factors are elevated ambient temperatures. In principle CH can decompose without exposure to significantly elevated temperatures: as is apparent from the spate of incidents leading down to 1998: see paragraph 65 (xvi) above. Dr Clancey had said in his 1974 paper that there was "*no evidence that high temperatures are a prerequisite [to accidents] although it would appear, on other evidence, that high temperatures may contribute*". He had also said that there would be a hazard "*so long as [CH] of the present quality*" was shipped. But by 1998 there was no evidence that the quality of the UN 1748 had improved.

97. UN 1748 CH had *variable characteristics* depending on the process of manufacture, the raw materials and the source. There was also an *increased risk with larger packages,* so that a 40kg container would present more of a risk than a laboratory test sample; and an assembly of packages in a container would present more risks still. The lower CATs for a container of material might lead to runaway decomposition and explosion if combined with warm surroundings such as warm waters or sources of heat (against which UN 1748 explicitly warned). In particular there was a well recognised risk that container loads could become dangerous at temperatures as low as 40ºC or below. CSAV stowed a cargo of UN 1748 next to a heat source in circumstances where there was every chance of a sustained temperature in excess of 40ºC, and must be taken to have accepted the risk of a consequent explosion.

98. There was also a recognised risk that commercially produced CH might contain iron oxide particles. The manufacture of CH gives rise to high levels of chlorine, which is highly corrosive and is liable to cause steel machinery to rust, the bagging nozzles being particularly prone to this happening. This

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[13] The experts agree that metal ions are known to affect thermal stability but there is no viable theory of those effects which would indicate what ppm of what metal ion would have what consequences.

problem occurs in factories in the USA and is likely to occur even more in China.

Discussion

99. Much of Sinochem's submission as to the known characteristics of CH in 1998 is acceptable in general terms: in particular the variability of CH (both as between one UN No and another and within the same UN No), its ability to decompose with the potential for thermal runaway, the significance of moisture content and size, and the possibility of explosion if drums are exposed to heat.

100. It is, however, necessary:

(a) to distinguish between one type of CH and another, i.e. between UN 1748, UN 2880 and UN 2008 (the latter two being recognised as more unstable than UN 1748);

(b) to recognise the attribution of incidents to rogue cargo; and

(c) to examine the position as at 1998. It is also necessary to have regard to specific figures.

101. As I have said, I do not accept that in 1998 a prudent carrier ought to have known that a container load of UN 1748 could explode if exposed to a temperature of less than 40ºC. The lowest CAT that the prudent carrier would have in mind would be the one specified in UN 1748 itself.

102. Sinochem relies on the fact that in December 1999 Dr Beeley had a discussion with Mr Lu Ming of Sinochem, who was not a trained chemist and whose main responsibility is said to have been importing rubber and steel, in which he showed himself familiar with the risk of a container load of UN 1748 becoming dangerous at less than 40ºC. However, by December 1999 the "Contship France" and "DG Harmony casualties had occurred, as well as the "Aconcagua. The press reports on these casualties (e.g. C6/218-9) must necessarily have had a major impact on the perception of traders and carriers. The material in question had been UN 2880.

103. Even though Dr Beeley's discussion with Mr Lu Ming concerned CH in general, and Sinochem only sold UN 1748 (the extent to which Mr Lu Ming understood there to be a relevant distinction between the three UN Nos being unclear), I do not regard this conversation as showing that in 1998 a prudent carrier would have appreciated that there was a risk that a container of quadritainers of UN 1748 might explode at 40ºC, 20ºC below the figure mentioned in UN 1748 itself. When it was suggested to Professor Gray that that risk was known before he carried out his 1999 work he said that that was new to him; and it would have been new to a prudent carrier.

104. Further, whilst it was known that, all other things being equal, the CAT would reduce if the size of the material in question increased, the effect of close

packing of a large number of drums was something about which in 1998 little was known. It was Professor Gray's research in 1999 that drew attention to the fact that two types of interaction needed to be considered. The first was the well known effect of increasing size reducing CATS e.g. having several kegs rather than one. This effect could be calculated for several kegs by using the F-K theory and taking the dimensions of a body comprising several stacks of kegs. The second was the interaction of the stacks of kegs with each other within an enclosure such as a container. The latter could be calculated by an "interaction" theory which he formulated in 1999.

What would the declaration of the goods as UN 1748 signify as to their characteristics?

105. There are two separate questions:

(a) What did the IMO and its Dangerous Good Sub-Committee intend UN 1748 to cover?

(b) What would a prudent carrier understand UN 1748 to signify?

Language

106. CSAV submits that the language used in the specification of UN 1748 supports its contention that no more than 1% moisture was permissible. The use of the word "dry" and the chemical formula $Ca(OCl)_2$ without reference to H_2O mean that the product is to be without moisture or, as it is often described (but not in UN 1748), "*anhydrous*"[14]. Contrast UN 2880 whose chemical formula is $Ca(OCl)_2.H_2O$ which denotes (a) the presence of moisture and (b) its presence as molecularly bonded water or water of hydration. Whilst other chemicals can be present (as is signified by the variable available chlorine percentage) water is not referred to. In practice it is virtually impossible to produce CH which is wholly without water but a leeway of 1% is the maximum allowed, as is confirmed by the history of the product and of the UN 1748 classification.

History

107. Calcium Hypochlorite Dry was first introduced as a proper shipping name/correct technical name in 1961. At that stage, as Mr Charlton's evidence confirmed, the product manufactured had a moisture content of up to 1%. It was described as "dry" or "anhydrous" (although the latter term was not then in the specification), which both in Greek and chemistry means "without water"; and the PSN used for it was "Calcium Hypochlorite, Dry" and "Calcium Hypochlorite Mixture, Dry".

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[14] Professor Gray cited a Dictionary of Chemical Technology which referred to CAS 7778-54-3 (UN 1748) as usually containing about 1% water; and to the Code of the National Fire Protection Association (USA) which describes Anhydrous (Dry) CH as containing less than 1% water.

108. In the early 1970s Penwalt, a US manufacturer of UN 1748, patented a hydrated version of CH under the trade name "Sentry". In the late 1970s the DGSC considered the topic of *hydrated* calcium hypochlorite. In August 1978 a proposal was put forward, on the impetus of Olin, the large US manufacturer, for a new entry in the IMDG code for calcium hypochlorite hydrated, with a draft UN number of 2880.

109. A note by the Secretariat of the DGSC entitled "*AMENDMENTS TO THE "INTERNATIONAL MARITIME DANGEROUS GOODS (INDG) CODE – Stowage of High Strength Calcium Hypochlorite*" and prepared for the 30th session of the DGSC recorded that the Working Group on High Chlorine Calcium Hypochlorite had divided into two factions (sic). The first, consisting of the United States and Poland, held that the material should be permitted below deck either palleted or containerised. The opposing faction, consisting of the United Kingdom and the Netherlands, maintained that on-deck stowage considerably reduced the severity of incidents. It also recorded that an entry for Calcium Hypochlorite, hydrated containing not less than 5.5 per cent and not more than 10 per cent water, Class 5.1, UN 2880, had been accepted by the UN Committee of Experts for inclusion in the UN Recommendations, which would necessitate a new entry in the IMDG Code; and that serious reservations had been expressed by the UK and Netherlands delegates that the critical temperature might be too low for safe transport.

110. Annexed to this note was a submission from the United States setting out its opposition to any on-deck limitation. An annex to that submission contained the following:

> *"1. Two species of High Strength Calcium Hypochlorite are presently transported on a world-wide basis. They are:*
>
> *.1 Dry (anhydrous) Calcium Hypochlorite containing up to 1% water; and*
>
> *.2 Hydrated Calcium Hypochlorite containing not less than 5.5 per cent water*
>
> *2. Both products are used extensively throughout the world as sanitizing products……*
>
> *3. At the twenty-second session of the UN Group of Rapporteurs, a new entry was adopted for Hydrated Calcium Hypochlorite. This entry was based on the fact that the properties of the anhydrous and the hydrated forms of Calcium Hypochlorite are significantly different.*
>
> *4. The hazardous properties of dry, High Strength Calcium Hypochlorite are no doubt well known to the members of the Sub-Committee. Approximately eight years ago, it was discovered that those properties could be significantly altered with the addition of from 5.5 to 10 per cent water. The incorporation of this amount of water, together with a*

> *reduction in the available chlorine to approximately 65 per cent yields a product that is still a strong oxidising agent but one which exhibits a greatly reduced activity.*
>
> *5. The principal difference between the two forms of Calcium Hypochlorite is that the hydrated form, unlike dry Calcium Hypochlorite, will not undergo a self-sustaining decomposition. The introduction of organic contaminants may cause an initial reaction, but it is localised and less vigorous than in the dry material., More importantly such contamination will not lead to a self-sustaining reaction in which the entire mass of material will decompose, unless there is an excessively large amount of contaminant present.*
>
> *6. A good correlation of the difference in reactivties is exemplified by the "lighted match and burning cigarette" test. While dry Calcium Hypochlorite in contact with either will immediately undergo a self-sustaining reaction, which continues until the material is decomposed, the hydrated Calcium Hypochlorite will take longer to react initially and the decomposition will be limited to the immediate area of contact and then will self-extinguish.*
>
> *7. It is therefore proposed that a new entry for Hydrated Calcium hypochlorite be included in the IMDG Code…"*

As is apparent from that annex, hydrated CH, which had started to be produced in about 1971, was thought to be much less sensitive to explosion or fire and not to support propagating radiation. If contaminated and rapid reaction ensued the reaction would, in contrast to UN 1748, cease when the material was consumed. In the event it was later to become apparent that the new material also had the disadvantage of a lower CAT and was much more prone to spontaneous exothermic decomposition.

111. In 1981 the entry for UN 2880 was finally adopted. At that stage UN 2880 provided for the hydrated form of calcium hypochlorite; and UN 1748 provided, as before, for dry calcium hypochlorite, which was then being produced with up to 1% moisture. There was, as Mr Charlton accepted neither consideration of nor debate about the introduction of an intermediate product with a moisture content between 1% and 5.5%.

112. Since that time the IMO and the DGSC have done nothing to change the meaning or scope of UN 1748, which, as Mr Charlton also accepted, was intended to reflect the existing dry (up to 1% moisture) product. There has been no discussion within the IMO about changing the correct technical name or PSN or the content of the entry for 1748; nor has any manufacturer or national body on behalf of manufacturers approached the DGSC in relation to a new market product consisting of a moisture content of between 1% and 5.5%.

CSAV's submissions

113. In those circumstances, CSAV submits, UN 1748 cannot be treated as covering the shipment of CH with a moisture content in excess of 1%. It submits, as I accept, that the recognised route for changing the meaning of an entry is to make a representation to the IMO. It is not open to a manufacturer to classify its goods under the wrong UN number and, by doing so, unilaterally to vary the criteria for the inclusion of material within a particular UN number. To do so would be likely to give a false or misleading indication of what was being shipped and the risks involved in carrying it.

114. For those reasons, both linguistic and contextual, as CSAV submits, UN 1748 meant, was intended by the IMO to mean, and was always understood to mean "dry" viz. anhydrous with moisture up to about 1%, from the time when it was introduced up to and including 1998.

Sinochem's submissions

115. Sinochem contends (a) that prior to the introduction of the UN 2880 category and since the 1970s CH has been manufactured and transported around the world by sea as UN 1748 with a moisture content in excess of 1%; and (b) that, with the introduction of UN 2880, it remained legitimate to declare product with a moisture content in excess of 1% as UN 1748 provided that it was less than 5.5%.

The international trade in CH before 1982

116. Sinochem accepts that before 1982 UN 1748 was principally manufactured with up to about 1% moisture, but submits that this was not exclusively so. The joint report refers at page 21 to tests carried out by Dr Faust of Olin to determine the lowest runaway temperatures of dry samples and samples containing moisture. One sample referred to in Appendix 14 is a Pittchlor sample with a moisture content of 4.5%, although whether that was exported is unknown. Sinochem also refer to the fact that the US submission of February 1979 records that two types of high strength CH were "*presently transported on a worldwide basis*".

117. The two types were (i) dry CH containing up to 1% moisture and (ii) hydrated CH containing not less than 5.5% moisture. The hydrated material must, Sinochem submits, have been transported as UN 1748 since there was then no other available number. This does not appear to have excited objection. Prior to 1982 it was, it submits, proper to export CH with water in excess of 1% as UN 1748 because there was no prescribed water content for UN 1748 and UN 2880 did not exist. Moreover it would have been inappropriate to export such a product under any "N.O.S" entry for the reasons set out in the following paragraphs.

"Not Otherwise Specified".

118. The Code provides as follows:

> *"5.1.11. Non-classified materials*
>
> *A "GENERIC" or "NOT OTHERWISE SPECIFIED (N.O.S) entry may be used to offer for transport by sea a substance, material or article which is not listed by its name in the General Index. Such a substance, material or article may be transported only after:*
>
> - *Its dangerous, hazardous and/or harmful properties have been determined*
> - *It has been classified in accordance with the class definitions and criteria; and*
> - *The entry that most accurately describes the nature of the goods has been selected…".*

UN 1479

119. UN No 1479 in Class 5.1 provides for an "OXIDISING SOLID N.O.S."

120. Neither party argues that CH with a moisture content over 1% and below 5.5% should have been declared as UN 1479.

121. Sinochem contends that that label could not be used because prior to 1982 CH, irrespective of moisture content, and, from 1982, CH with a moisture content below 5.5%, appeared in the General Index as "CALCIUM HYPOCHLORITE, DRY". Further UN 1479 contains no requirement that the substance should be stored away from heat. It would make no sense for the stowage conditions to be relaxed for a product with a greater quantity of moisture, a characteristic known to increase thermal instability.

122. CSAV contends that "CALCIUM HYPOCHLORITE, DRY" was *not* the name of a product with a moisture content in excess of 1% but of a product with up to 1% moisture. Nevertheless a product with more than 1% moisture could not be declared as UN 1479 because its "*dangerous, hazardous and/or harmful properties*" had not been determined.

123. The common ground between the parties that UN 1479 was inappropriate casts no light on the ambit of UN 1748. It is agreed to be inapplicable whoever is right on the issue of the permitted moisture content of UN 1748.

UN 3212

124. UN No 3212 relates to "HYPOCHLORITES INORGANIC N.O.S." Both parties regard it as an inappropriate category for the same reasons; although, as Sinochem observes, it does, at least, have the same properties, observations, and packing stowage and segregation requirements as UN 1748. However, no one appears ever to have discussed it as applicable to calcium hypochlorite: possibly because the entry refers only to pure hypochlorites.

The international trade in CH after 1982

125. Sinochem contends that *after* 1982, CH with up to 5.5% water has regularly (and properly) been exported as UN1748, and not only by manufacturers in developing countries, but also by some of the largest manufacturers in the western world. It relies on a number of separate matters.

126. Firstly, in Appendix 4 to his report Mr Charlton gave details of research which had identified 17 companies which manufactured or distributed CH which identified their CH product with a water content in excess of 1% as UN 1748. Of those **9** (Nos 1- 4, 6-8 and 10-11) are Chinese, who may or may not be manufacturers; and of those nine 2 entries are dubious: one (No 4) has a UN Number 1780 (sic) and another (No 6) is said to be "*UN 1748 tbc*". In **2** cases (Nos 12 and 20) the companies were Australian distributors. In **1** case (No 14) the company was a Canadian distributor of "Pulsar Plus" tablets (an American product). In **2** (No 15 & 16) cases the company is Arch Chemicals Ltd ("Arch"), now the world's largest supplier in the USA. In **1** case (No 18) the company is Olin Corporation, a very large US supplier now taken over by Arch. **1** case (No 17) involves another US company. **1** case (No 19) involved a UK distributor of "HTH Easy Flo" tablets manufactured by Arch.

127. CSAV submits that nothing significant can be derived from this research. All it shows is this: (i) some Chinese manufacturers, who may well have been "*untutored*" as to the requirements[15], wrongly declared product with moisture in excess of 1% as UN 1748; (ii) two Australian distributors and one UK distributor also wrongly declared as UN 1748 a product with up to 5.5% moisture, of unknown origin (maybe China), (ii) the Canadian and US companies declared as UN 1748 goods with a moisture content up to 8.5 or 10%, which, on no view, was permissible.

128. Second, in December 1999 a Japanese working group (chaired by Prof. Uehara) presented as UN1748 CH with a moisture content of 4.2%. It did so in a report of 3rd December to the DGSC of heat storage testing carried out in order to evaluate the risk involved in the transport of Japanese CH export products.

129. Third, in a report of 10th December 1999 the United States submitted to the DGSC information from North American producers of CH that UN1748 was *"generally lower in water content"* than UN2880. This is a different description from that given by the USA in 1979 (see para 110 above), and appeared to allow for UN1748 having water content up to the lower limit for UN2880.

130. Fourth, in 2000/2001 Dr Beeley obtained a small sample of anhydrous CH from Tianjin from Magnesia, a small German trading house. It was

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[15] Consistently with the fact that the chemical formulae quoted by Chinese manufacturers for CH are often wrong: see Prof Gray 1 paras 6.2.8 -6.2.11.

shipped from Germany, presumably as UN1748. It had a moisture content of 2.1%.

131. Fifth, in March 2001 a sample which came to be known as Sample A (see paragraphs 158ff below) was shipped by John Kellys (London) Ltd – merchants trading in (inter alia) chemicals – from Rotterdam to Professor Gray in Australia at Dr Beeley's request. The reported moisture content was 2.7%. The material was declared to the carrier as UN1748. Neither John Kellys, Dr Beeley nor Professor Gray appear to have regarded the classification as UN1748 as inappropriate at the time.

132. Sixth, in April 2004, Dr. Beeley learned (as is recorded in his contemporaneous notes) that the Donghai factory produced UN1748 with a maximum moisture content of 3%.[16] Reference was also made in the note to a *"normal range"* of 1.1% to 2.95% and to two separate grades: 0.5% to 2.5% and 0.25% to 1.5%. Dr Beeley was told that the higher range of moisture content was for domestic and the lower for export. Each of these ranges or grades embraces material with moisture in excess of 1% and up to 5.5%, some of which is evidently exported as UN1748.

133. Seventh, in 2004, samples of UN1748 ex Sinochem and Franmar were procured with moisture contents in excess of 1%.[17] The sample ex Franmar was exported as UN1748 from Chile to the UK.

134. Eighth, in 2005 the US Department of Transportation Pipeline and Hazardous Materials Safety Administration ("PHMSA") in response to an e-mail from Mr. Rory Butler of Holman Fenwick, CSAV's solicitors, asking for the permissible moisture content of UN 1748 responded:

> *"The HMR [Hazardous Materials Regulations] do not specifically address the permissible moisture content of calcium hypochlorite, dry. However, as your e-mail notes, Calcium hypochlorite, hydrates (UN 2880) has a specific range of not less than 5.5. per cent but not more than 16 per cent water. Therefore, the moisture content of Calcium hypochlorite may not exceed 5.5 percent in order for the material to be classed as "Calcium, hypochlorite, dry".*

135. Ninth, to this day Arch Chemicals Ltd of America produce and transport as UN1748 Pulsar Plus Dry Chlorinated Briquettes comprising 4-10% water.

Paragraph 7.1.10 of the Code

136. Paragraph 7.1.10 of the Code provides that :

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[16] This is reflected in Dr. Beeley's contemporaneous notes and in the marketing brochure he was given at the time.

[17] The Sinochem samples had moisture contents ranging between 0.38% and 1.22%. The Franmar sample had a moisture content between 1.63% and 2.81%.

> "*Hydrates of inorganic substances may be included under the equivalent proper shipping name for the anhydrous substance, as appropriate.*"

137. Mr Charlton suggested that, in the light of that provision, it was open to Sinochem to declare CH with a moisture content in excess of 1% but below 5.5% as UN 1748. He accepted, however, in my opinion correctly, that it would be inappropriate to ship a hydrate as the anhydrous substance pursuant to paragraph 7.1.10 if the hydrate demonstrated different thermal stability or hazard characteristics. In such a case it would be necessary to have a separate provision for the hydrate. That is, no doubt, why, in the late 1970s and early 1980s, when a new entry for UN 2880 was being considered, the IMO did not take the view that the hydrated material could simply be shipped under UN 1748 pursuant to paragraph 7.1.10; and why, when considering expanding the entry for UN 2880 to include hydrated calcium hypochlorite containing up to 16% moisture, the IMO did not take the view that that material could simply be shipped in the same way. He also accepted, in the light of Professor Gray's results, that moist material up to 5.5% presents different thermal stability characteristics from the 1% material.

138. There is a second problem with using paragraph 7.1.10. In order for it to be applicable it is necessary that CH with a moisture content of up to 5.5% moisture is a "hydrate". I accept Mr Charlton's definition of that term in evidence as "*a chemical compound which has generally water of crystallisation or water bound to it*". A merely moist form of dry calcium hypochlorite is not a hydrate and will only be so if the formula is that for UN2880, viz. $Ca(OCl)_2.H_2O$ (however many molecules of water are bound with the calcium hypochlorite) and if the molecules are bound as water of crystallisation. The product shipped in the present case did not fulfil these conditions.

139. For these reasons it does not seem to me that reliance can be placed on paragraph 7.1.10.

Chemical formulae

140. Sinochem contends that a conclusion that CH with up to 5.5% water is properly classified as UN1748 is supported by the chemical formula attributed to that product in the IMDG Code namely: $\mathbf{Ca(OCl)_2}$.when compared with the formula attributed to UN2880: $\mathbf{Ca(OCl)_2.H_2O}$.

141. Neither formula is strictly accurate. $Ca(OCl)_2$, the formula for calcium hypochlorite, makes no allowance for the presence of any water despite the fact that UN1748 may (on CSAV's case) contain up to 1% water. Similarly, the notation "$\mathbf{.H_2O}$" for the hydrated material suggests one molecule of CH bonded with only one molecule of water. This is not necessarily the case.[18]

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[18] Mr. Charlton thought that the use of a small "n" before "H2O" would have been more appropriate. This would signify that any number of molecules of water could be bound with the CH. The formula appeared in this form when an entry for UN2880 was originally proposed.

142. Mr Charlton's evidence was that the intended distinction between the two products was, essentially, as follows. CH (in whatever form) comprises a mixture of molecules. It contains the anhydrous species (expressed as $Ca(OCl)_2$), the monohydrate (expressed as $Ca(OCl)_2.H_2O$) and the dihydrate (expressed $Ca(OCl)_2.2H_2O$). Each will be present in varying proportions depending on how much drying is performed by the manufacturer. In the case of UN 2880, the hydrated material will be the major CH component after drying, hence the formula $Ca(OCl)_2.H_2O$. In the case of UN1748, the anhydrous material will be the major CH component after drying, hence the formula $Ca(OCl)_2$. This is so even where the CH contains up to 5.5% water.

Discussion

143. The IMO has been asked to clarify the permitted moisture content of UN 1748 but has so far failed to do so.

144. It seems to me clear from Mr Charlton's evidence (and the US submission in 1979) that when UN 1748 was introduced as a category in 1961 the CH then being produced had a moisture content of up to 1%. That was the material that the DGSC had under consideration and for which UN 1748 was designed to cater. The DGSC did not, however, incorporate into the specification for UN 1748 any maximum moisture content. It may not have thought it necessary to do so either because there was no material then being produced with a moisture content in excess of 1% or because its members thought that the description "dry" and the chemical formula $\mathbf{Ca(OCl)_2}$ signified that there had to be minimal moisture, of which 1% may be regarded as an upper limit, being a limit which in practice manufacturers would be able to meet. It may simply not have addressed its collective mind to how CH with more than 1% water should be described.

145. The absence of any *specified* limit has had the consequence that some manufacturers and shippers have declared material as UN 1748 whose moisture content exceeds 1%. In relation to the period prior to 1982 when there was no UN 2880, material with a water content in excess of 1% (or 5.5%) water content is likely to have been declared as UN 1748, presumably on the basis (insofar as thought was given to the question) that it was, indeed, a hydrated version of CH and had no worse thermal characteristics (although the latter consideration may not necessarily have been in the minds of those concerned). The 1979 US submission proceeds on the basis that the hydrated product was in some respects safer.

146. In respect of the period from 1982 onwards Mr Charlton's list shows that some manufacturers and other companies have used UN 1748 when it was plainly inapplicable e.g. because the moisture content equals or exceeds 5.5%. But in some cases they have used UN 1748 for product which exceeded 1% but was less than 5.5%. On Mr Charlton's list these instances, other than the Chinese, are few. There are, however, other instances of material with moisture > 1% and < 5.5% being treated as UN 1748. Whilst it is possible to regard all the instances, whether on the list or not, as simply a wrong use of UN 1748 (perhaps with a view to avoiding compliance with requirements

imposed by shipowners in respect of the carriage of UN 2880) they seem to me indicative that some people genuinely understood that such material could properly be declared as UN 1748.

147. I do not regard it as useful to seek to determine what was in the minds of the IMO or the DGSC in 1961, 1982 or 1998 so far as the moisture content of UN 1748 was concerned. It is not possible to know. I have no evidence from the IMO or the DGSC and the fact that, despite request, no clarification has yet been forthcoming means that there is no authoritative statement of what the IMO intended or, at any rate presently intends, UN 1748 to cover. Mr Charlton's explanation of the intended distinction between UN 1748 and UN 2280 might be right; but I have no means of knowing whether that was what was in the minds of those concerned with framing the relevant specifications.

148. The more important question is what the terms of UN 1748 must be regarded as conveying in 1998 to (i) a prudent carrier seeking to understand the characteristics of what was being presented to him for carriage and (ii) a shipper anxious to know how he should legitimately label his goods. Neither the shipper nor the carrier is required to be an expert in the internal workings of the DGSC nor would they have, nor should they be expected to have had, knowledge of material such as the US 1979 submission or any other material casting light on these inner workings. Such material is not readily available.

149. In my judgment the terms of UN 1748 do not sufficiently convey that there is an upper but unspecified limit of 1% moisture, such that a prudent carrier would be entitled to expect that material shipped as UN 1748 did not have a moisture content in excess of 1% and a prudent shipper would be bound to realise that he could not declare product with a moisture content in excess of 1%. The use of the word "dry" and the chemical formula $Ca(OCl)_2$ could be taken to have that meaning. But the criterion "dry" is either practically impossible (if it means 0% moisture) or inexact, and the formula is exact but practically impossible.

150. Further UN 1748 is not to be looked at alone. In order to determine how a material can or should be declared it is often necessary to look at more than one UN number to see how the product in question fits in with the scheme of the Code. In circumstances where there was in 1998 both UN 1748 specifying that the product must be "dry" and UN 2880 which refers to 5.5% moisture and above it seems to me that a user of the Code in the position of a shipper would be entitled to think that below 5.5% was the upper limit for the dry material; and that a carrier would not be entitled to assume that material described as UN 1748 had a moisture content no higher than 1%. That was the view taken by the US Department of Transportation, even though they may have been prompted to it by the terms of the request made to them. Their view is in no way conclusive (CSAV submits that it is simply wrong – the "therefore" is a non sequitur) but it is indicative of how UN 1748 could be judged by a reasonable and conscientious reader.

151. As is apparent from the last paragraph the question of what UN 1748 signified must, in my view, be asked as at 1998 because it was in 1998 that the answer

fell to be acted on. Users of the Code in 1998 may well have been legitimately "untutored" as to what the position was decades before. If UN 1748 was unambiguous it might well be impossible to accept that some later introduced UN number had any relevance. But in the present case UN 1748 is not unambiguous and when read with UN 2880 appears to indicate that 5.5% is the lower limit for the hydrated product and consequently that the upper limit for the dry product is immediately below that.

The characteristics of UN 1748

152. The central question is whether the CH shipped on the "Aconcagua" possessed the characteristics of UN 1748 of which CSAV had or ought to have had, knowledge. Material with such characteristics is often referred to as "normal" since the attributes which a material normally possesses will normally be known, or at any rate should be[19]. I refer hereafter to normal material in the sense of material with the characteristics of which a prudent carrier ought to have had knowledge.

153. Sinochem are right, in my judgment, to submit that, since UN 1748 covers a spectrum of material with variable characteristics, a prudent carrier must anticipate that the cargo declared to him as UN 1748 may be at the most dangerous end of the spectrum of normality and takes the risks inherent in carrying a cargo which is the most thermally unstable product that can properly be regarded as normal.

154. The resolution of the central question is rendered more difficult by three matters. Firstly, the characteristics of CH are variable. Secondly, Sinochem has produced no analysis (whether by itself, Jingang or anybody else) of the CH shipped, nor any quality control or manufacturing process data, nor details of any manufacturing standards applied in relation to it or to any other UN 1748 shipped at about the same time. Thirdly, no useful sample of what was shipped on the vessel is available. The factory ceased operations in 2004. Fourthly, samples of UN 1748 were in 2000 and onwards not readily obtainable.

The search for samples

155. CSAV's search for samples was as follows. In 1999 samples had been taken of the residues inside the remains of the container on board the "Aconcagua". These were analysed by Minton, Treharne and Davies Ltd. But they were of no real value because they were bound to have been contaminated by the fire and the efforts to put it out.

156. In June 2000 CSAV made available to Owners a sample which was said to be from the same source as the "Aconcagua" cargo, which was analysed by Butterworth. That also was of limited value. There is no documentary

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[19] But this may not inevitably be so. It is possible to imagine a, no doubt rare, material which invariably, usually, or regularly and, therefore "normally", has a particular attribute of which a prudent carrier could not be expected to be aware

evidence as to its origin; it was said to have been delivered in an unsealed container; and is likely to have been contaminated. This would account for its low available chlorine value of 49.2%.

157. In 2000/2001 Dr Beeley set out to procure commercial samples of dry CH. The history of his quest is as follows.

Sample A

158. In February 2001, Dr. Beeley purchased a bulk sample of granular CH from John Kellys (London) Limited ("Kellys"). That sample was – as at 19th February – held by Kellys in Rotterdam: see their letter of that date. Kellys described it as having a chlorine and moisture content of 66.5% and 2.7% respectively. Dr. Beeley was told that it originated from Southern China.

159. The sample, which came to be known as "Sample A", was packaged in 38 40kg net steel drums. which were then stuffed inside a 20ft reefer container which was shipped by agents for Kellys on board the "PEGASUS BAY" at Rotterdam for carriage to Sydney. The cargo was declared as UN1748. The drums were delivered to Professor Gray in Sydney in April. They were white cylindrical steel drums bearing hazardous goods labels. Unlike some of the Jingang material (see para 161 below) it had no particulate contamination. Upon analysis by Professor Gray, Sample A was found to have an available chlorine level of 58.4% and a moisture content of 5.8%. This is a moisture content which falls within UN 2880. But Professor Gray found by X ray diffraction that the chemical composition of Sample A was that of the "dry" and not the hydrated form of CH. Its water was not present as water of hydration[20]. The reason for the discrepancy between 5.8% and 2.7% is unknown. Sample A was also analyzed by ICP Analysis for the presence of metal ions. It was found to have an iron and magnesium content of 340ppm and 1070ppm respectively. These results were said to be accurate to within +/- 10%. They are significantly lower than the equivalent results for the samples provided by Kellys later in 2001.

160. It is not possible to say where precisely Sample A came from; when and in which factory it was produced; at what point the drums were stuffed inside the container; in what conditions and by what means they were stored and transported between production and shipment; and precisely when the chlorine and moisture contents reported by Kellys were measured and by whom.

Samples ex Donghai, Zhenjiang and Jingang

161. In March 2001, Dr. Beeley purchased three further bulk samples of about 2 tonnes each of CH from Kellys, who were asked to supply *"normal"* dry CH in plastic quadritainers. Their invoices issued in June 2001 record that the samples originated *"ex Jingang Tianjin Factory", "Ex Donghai Tianjin*

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[20] Water of hydration will reduce thermal stability. It is not clear whether water which is not water of hydration has that effect. The water present may well have been produced by decomposition, which makes a material more stable.

Factory" and *"Ex Zhenjiang Factory."* It was not known at the time of the order that the cargo laden on the "Aconcagua" had been manufactured in the Jingang factory because Sinochem had failed to disclose from which factory or manufacturer the product had been shipped.

162. Certificates of analyses issued by Kellys at the same time record the following:

	Type	**Chlorine (%)**	**Moisture (%)**
Zhenjiang	Powdered	65.45	0.92
Donghai	Granular	65.62	0.80
Jingang	Granular	65.62	0.80

163. The material in question was, like the CH on board the "Aconcagua", manufactured by the calcium process, involving the chlorination of a slurry of lime (calcium hydroxide), as opposed to the sodium process, where lime is chlorinated in the presence of sodium hydroxide.

164. The contract notes described the packing as "*U.N approved Polydrums*". The invoices describe the samples as packaged in U.N. approved packing (which was not further described). The drums (as they were described on the bills of lading) were then transported *"from origin"* to Hong Kong where they were stuffed inside a reefer container. On 17 June, that container was shipped on board the vessel "MAERSK PLYMOUTH" at Hong Kong for carriage to Sydney. The goods were declared as UN1748. The name given for the shipper in the bill of lading is "Bachmann (HK) Ltd", although there may be other letters before the "B".

165. In July 2001 the 3 samples were delivered to Prof. Gray in Sydney. They arrived in blue steel drums which appeared to Prof. Gray to be identical. The Donghai and Jingang drums were about 45kg net weight; the Zhenjiang about 50 kg. The labels affixed bore the name *"Northchem"* and *"Ex-Donghai", "Ex-Jingang"* or *"Ex-Zhenjiang"*.

166. Initial testing conducted by Prof. Gray produced the results set out in the table below. The iron and magnesium results are said to be accurate within +/- 10%:

	Chlorine (%)	**Moisture (%)**	**Iron (ppm)**	**Magnesium (ppm)**
Zhenjiang	64.4	0.33	540	1460
Donghai	62.9	0.21	600	1690
Jingang	60.4	0.37	720	1440

167. Between June and August 2002, further testing was performed by Prof. Gray on individual drums of the Jingang material.

Sample ex Franmar

168. In March 2004, 50kg of granular UN 1748 was procured from Franmar, for whom the CH on the "Aconcagua" had been intended. The CH was exported from Chile to the UK where it was analysed by Critical Processes Ltd. Upon analysis, the sample exported was found to have a moisture content ranging between 1.64% and 2.81%.

Sample ex Sinochem

169. In 2004, Sinochem sold to CSAV three 50kg drums of UN1748. These samples were reportedly manufactured by the Nanke Fine Chemical Company in Tianjin. The samples sold took three forms: powdered, granular and mixed. When Sinochem provided a quote in respect of these samples, it was understood that each would be of 65% strength and have 3% water. However, subsequent testing in China revealed results inconsistent with this. Across the three drums, the chlorine content varied between 59.6% and 63.1%. The moisture content likewise varied between 0.38% and 1.22%.

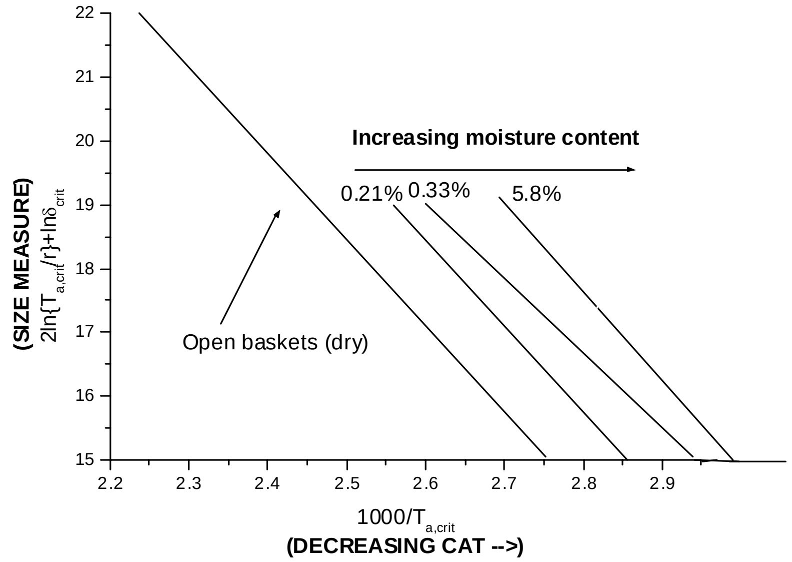
Determining CAT

The method

170. Professor Gray carried out experimental testing in order to discover the CAT of the samples. This involved placing samples of a given size inside a thermostatted oven at a given temperature with thermocouples inserted into the samples in order to measure the internal surface temperature. His method was as follows. If the sample did not ignite the test was treated as sub-critical and the process was repeated (if necessary more than once) with a fresh sample at a higher temperature. If the sample ignited the mean oven temperature between the higher temperature (the lowest for ignition) and the previous temperature (the highest for sub-critical) was taken as the CAT. The difference between the two temperatures should be 3 or 4 degrees at most.

171. Once the CAT of a given size sample had been determined tests were repeated with samples of a different size. The larger the sample size the lower will be the CAT. The procedure was repeated until a range of samples has been produced from which it was possible to extrapolate a CAT for a larger size body. Professor Gray's tests were carried out, firstly, with stainless steel gauze equicylindrical open baskets ranging in radius from 925mm (2g) to 175mm (35g); and, secondly, using commercial steel cylindrical drums lined with plastic bags, together with smaller commercial 10 litre and 20 litre HDPE cylindrical drums and new steel paint tins of various sizes down to 1 litre with plastic liners. The open tests are of limited value for present purposes because any moisture contained in the sample can be lost by evaporation, as a result of which the time to ignition is prolonged because the material is initially cooled by the evaporation process.

172. It is customary to plot the results of these tests on a figure in which the vertical axis is a measurement of the size of the sample and the horizontal axis is the inverse of the CAT. Thus, although the figures on the horizontal line running from left to right *increase*, they represent a *decreasing* CAT. This is represented in Prof Gray's figure 10:



173. The slopes headed by the figures "0.21%, 0.33%, and 5.5%" are the results for Donghai, Zhenjiang and Sample "A" respectively. The figure thus shows CAT reducing as the water content of the samples increases. As can be seen the slopes are broadly parallel and do not cross, and move to the right as water content increases.

174. There are a number of further matters to be stated. Firstly, standard F-K theory holds that for any given material the CATS plotted against size should fall on a straight line. If the experimental results fall on a straight line, extrapolations can be made with some confidence of CATS for larger sizes. Secondly, marks on the graph plotting the CATS derived from actual experiments are unlikely to lie in a completely straight line. Whether or not a straight line can be plotted is conventionally determined by the "least squares" method. This is a well established statistical technique for treating experimental data which in the nature of things will produce "scatter" as a result of factors that cannot be controlled. The method assumes that the "noise" which causes the points to deviate from the straight line is random with no bias in any direction. The line of best fit is that line in respect of which the vertical distances from the line to each point when squared and added together will be the minimum. Using that methodology Prof Gray was able to draw appropriate straight lines through his marks save in respect of Drum 42 of the Jingang material where the results showed deviations from F-K theory that were very much larger than other drums and from which Prof Gray felt unable to draw any conclusions.

175. Thirdly, the slope enables one to derive two thermodynamic characteristics of the material – the activation energy (-E/R[21]) which is derived from the slope of the straight line, and the pre-exponential factor (QZ/K), which is given by the point of intersection with the vertical axis. The activation energy is a measure of the sensitivity of a reaction rate constant to temperature. A small activation energy means that the reaction will tend to be more significant at lower temperatures than if it were large. The QZ is a measure of the absolute size of the reaction rate constant and is independent of temperature. Large values will, all other things being equal, lead to lower CATs.

CATs for Uehara, Zhenjiang and Donghai

176. Professor Gray found that his measured CATs for a full commercial package of 35cm diameter (40kg) of Zhenjiang and Donghai material married with that reported by Uehara as follows:

Material	**CAT**	**Moisture content**
Zhenjiang (powder)	69.3°**	0.33%
Donghai	77.6°**	0.21%
Uehara	77.6°	1.02%*

** Figures taken from Appendix 1 to Gray 1. Table 8 has 69.7ºC and 77ºC.

* Reported by Professor Gray as ≤1% - but the Uehara results show 1.02%.

177. Leaving aside the Zhenjiang as being powdered material, Professor Gray benchmarked the “Donghai” material as constituting “normal” material for granular CH with 1% or less moisture content. Both Donghai and Zhenjiang behaved in a reproducible manner when tested consistently with expectations, suggesting consistent thermal stability. Further the similarity of results between Uehara and the other two products could be taken as a representation of the normal or expected behaviour of UN 1748.

178. Using standard F-K explosion theory Prof Gray calculated the CAT for a quadritainer of Donghai as 75.8ºC. (Zhenjiang was 68.4ºC). The degree of self-heating of this material, and, therefore, of heat generated, at an ambient temperature, whether of 30ºC or 50ºC, would be negligible.

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[21] Strictly the activation energy divided by a constant.

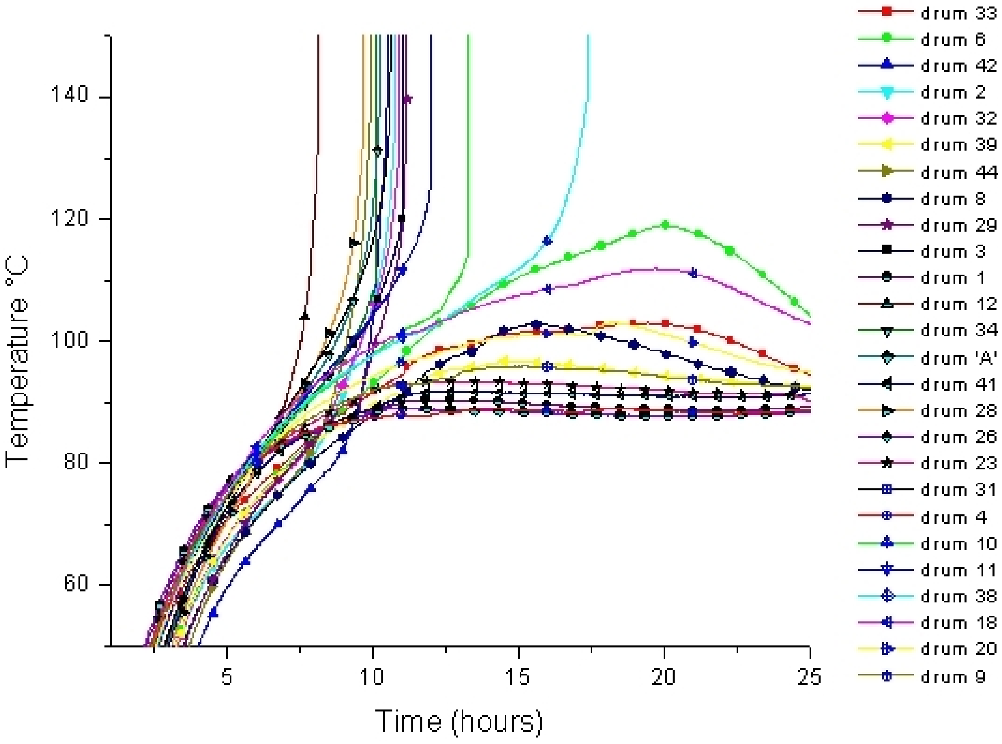
Sample A

179. The CAT for a 45kg package of Sample A was 62.2ºC and 67.5ºC for a quadritainer.

Jingang

180. Professor Gray's initial tests in 2001 were based upon random samples taken from the Jingang, Zhenjiang and Donghai drums and from the Sample A lot. The latter three produced results which were consistent. The Jingang material on the other hand produced inconsistent (and non reproducible) results. Thus, for instance, one 47.5 kg drum was supercritical at 72.6ºC and another was sub critical at 75.1ºC. The Owners, by whom Professor Gray was then instructed, asked him to proceed with testing on each of the remaining drums. This took place between June and August 2002. It produced widely variable results from drum to drum in respect of both moisture and available chlorine content. Visual inspection revealed particulate contamination with a rust like appearance. As a result Professor Gray carried out extensive further testing comparing the thermal behaviour of material from different drums. This included individual testing for CATs of particular drum contents for various size samples and simultaneous testing of 4 litre samples from all drums of the Jingang lot.

181. The result of the *comparative ignition tests* for the 26 4-litre samples held at a constant temperature of 87.6ºC revealed a widely varying pattern: see below. 12 drums did not ignite but displayed differing degrees of sub-critical behaviour. The rest had widely varying time to ignition. The tests also revealed that increasing moisture content was not the only thing that caused increasing thermal instability and indicated the existence of some other destabilising factor:



182. The CAT tests for *individual* drums were carried out on representative samples in different ranges of moisture content and different sizes of test drum. The results varied widely. For instance the 20 litre CATs varied from 67ºC to 83.8ºC; the 10 litre CATS from 75.1º C to 87.7ºC and the 4 litre CATs from 74ºC to 90.6ºC. Some of the drums tested had very low available chlorine (down to 53%). The results of individual tests for 4 litre samples were as follows:

Sample	**Donghai**	**J 5**	**J 7**	**J 12**
Water content	0.21%	1.0%	2.5%	3.5% Also large amounts of iron present
Prof Gray calculated CATs per quadritainer	**75.8°C**	**65.5°C**	**53.5°C**	**51.8°C**

183. A number of points arise. Firstly, Professor Gray's calculated CATs are based on results obtained in test oven conditions which involve strongly convective air. The air inside a shipping container is more quiescent and the material would probably explode at lower temperatures due to lower heat loss rates. Secondly, the degree of self-heating at an ambient temperature of 30ºC or 50ºC would be considerably greater in the case of Jingang Drum 12 as compared with Donghai. Thirdly, containerisation to some extent produces a lagging effect, as a result of which the ability of heat to dissipate is reduced, and the CAT is accordingly also reduced. Fourthly, Professor Gray's calculation in respect of containers rests on his interaction theory, which is explained in Appendix 9 of his 1st Report. Its aim is to describe the behaviour of self-heating bodies when a thermal resistance such as a container is placed between them and the ambient temperature (in this case of the hold). The theory[22] assumes that the air between the drums of material and the container walls (which represent the boundary layer) is well stirred and does not contain any temporary gradients.

184. Professor Gray also calculated that, even assuming that the container walls on the "Aconcagua" all reached a temperature of 50ºC the effect on the Donghai and Zhenjiang samples would have been minimal (a rise in temperature of about ½ º).

What conclusions can be drawn from Professor Gray's results?

185. Sinochem submits that no inference can be drawn from the Uehara. Donghai, or Zhenjiang results that the Donghai material should stand as any form of benchmark of the proper attributes of UN 1748. The Uehara material was produced in Japan, not China; and by the sodium and not the calcium process. Although originally granular in form and used in that form, for thermal ignition tests it was finely pulverised for thermal analysis. It had a moisture content of 1.02%. Clancy's samples B & C had produced a CAT of 70ºC - less than Uehara's 75ºC. As to the Donghai material, Sinochem submits that (a) the provenance of the samples obtained is dubious; and (b) CSAV has failed to establish that any one of the Uehara, Donghai samples is representative of the most thermally unstable product that can properly be classified as normal UN 1748.

Authenticity and provenance

Sinochem's submissions

186. Kellys ordered the material from Northchem. But it is wholly unclear how many intermediaries there were in the chain of contracts between Northchem and the manufacturer. The fact that "Bachmann (HK) Ltd" is the shipper suggests that there was at least one. The fact that the initials of John Kellys,

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[22] Expounded in "On the critical conditions for an assembly of interacting thermons" (2001) Anziam J (3,1-11).

i.e. JKM, appear on the labels on the steel drums under Northcem's name does not mean that there was a direct contractual link between Northchem and Kellys.

187. Dr Beeley asked for normal UN 1748. He provided no specification to Kellys and we cannot tell what requirements, if any, passed down the contractual chain as to (a) quality or attributes, including age, of the material; (b) the importance of differentiation of material as between one factory and another; or even (c) that the goods should be for export. The quantity of material ordered was much less than that of a normal shipment. Northchem and any other intermediaries may, for reasons of convenience or economy, not have bought material from each manufacturer as fresh product. Instead they may have put together a job lot obtained from the manufacturer, possibly from old stock, and/or from other intermediaries and/or from their own stock, and the product of one manufacturer may have been mixed with that of another.

188. It is further possible that the samples were transferred from plastic drums in which they were originally into the steel drums in which they arrived. Dr Beeley asked for plastic drums and the contract notes referred to polydrums. The steel drums in which the material arrived have Northchem labels on them not superimposed over any previous label. This suggests either that the material was originally packed into steel drums without labels and sent to Northchem who put the labels on, or that the material arrived packaged in plastic drums and was then transferred into steel drums by Northchem. The drums themselves may not have been new. Some writing which appears to relate to some other transaction is faintly detectable on the steel (e.g. a reference to "39 KG" in the photograph at C1/103). Rust on the drums might well have contaminated the product on any transfer.

189. In addition little is known of Northchem. A Google search turns up *Northcem (Tianjin) International Trading Co Ltd*, which may or may not be the 1998 supplier. I was told that Sinochem has not succeeded in getting any answer from the telephone number on the website. Mr Wang Fei, who was in 1998 Sinochem's vice general manager, said he had found it impossible to find out anything about them. Further, Northchem may have been inexperienced in the international shipment and carriage of CH. Their labels do not appear to comply with the requirements of the Code that they be durably marked in such a way that the information contained in them will still be identifiable after at least 3 months' immersion in the sea. See paragraphs 7.2.1.1 and 7.2.1.3/4 . Nor is there a distinctive label denoting the hazardous properties of the goods by means of colours and symbols and with the sub-class number in the bottom corner: paragraphs 7.2.2.1.and 8.1.Who put the English language labels on, where and when is unknown. Nor do we know what he knew about what was inside the drums. He probably did not speak English.

190. Lastly in view of the divergence in chlorine and moisture content between that reported by Kellys and that found by Professor Gray it is possible that the samples which gave rise to the results reported by John Kellys were not samples of the material actually supplied to Professor Gray. Further the thermal stability of the samples may have been affected during the voyage to

Hong Kong. In the light of all these considerations Professor Gray's results must be treated with caution.

Discussion

191. I accept that the evidence as to the provenance of the samples is less satisfactory than it could have been. I do not however accept that it should be looked at with quite the circumspection that Sinochem suggests.

192. Firstly, whilst there might have been a chain of intermediaries, the likelihood, as it seems to me, is that Kellys obtained the goods from Northchem who either obtained the material from the three factories or had it in stock, having previously obtained it from them. There are no indicia on the drums that anyone was involved other than Northchem and no apparent reason why there should have been an extended chain. I do not regard the fact that a Hong Kong corporation was named as the shipper in the bill of lading as likely to mean that there was an intermediate Hong Kong distributor.

193. Secondly, it is possible that the material was originally in 45 kg plastic drums which were then decanted into steel drums, and that, in the process, moisture or particulate matter was introduced (although is inherently implausible that, if that happened, only Jingang material was affected). But such decanting seems to me very unlikely, being time consuming, costly and unnecessary[23]. It is common ground that Chinese manufacturers offer shipment in plastic quadritainers or steel drums: see the Experts' Memorandum, para 20 and Donghai's 2004 brochure which shows blue quadritainers and blue steel drums, the latter being very similar in appearance to the drums delivered to Professor Gray. The idea that the change was a Northchem marketing exercise is unrealistic, particularly when the consignment was small and the labels indistinctive. If Northchem understood that the product was intended for someone like Professor Gray the marketing theory becomes even more unlikely. If marketing was the objective it could more readily have been secured by putting a Northchem label on the original plastic quadritainers. The steel drums may well have been delivered to Northchem unlabelled after which Northchem put on labels; or Jingang may have put on labels supplied by Northchem.

194. Thirdly, it does not seem at all likely that the products, separately labelled "ex Donghai, "ex Zhingiang" and "ex Jingang" have got muddled up. Powdered Zhingiang is unlikely to have been confused with, or for, granulated Donghai and Jingang. If it had been, that would have been immediately apparent. The fact that all the Donghai and Zhinjiang samples were internally consistent (and consistent with Uehara material) shows that they were the same material. The fact that the Jingang results were widely variable shows that this was a material in a class of its own. It is impossible to suppose that random or mixed up labelling of three different products could have produced those results.

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[23] It would involve emptying the product through a relatively narrow neck of a quadritainer into a drum (obtained for the purpose) and then disposing of the quadritainer.

195. Fourthly I regard it as unlikely that the material delivered to Professor Gray was not the material ordered by Dr Beeley. The drums all bear labels (JKM 30870/1/2) which correspond to the JKM numbers on the certificates of analysis.

196. Fifthly while it is possible that the Jingang material was assembled, as Mr Bright put it, from bin ends cobbled together, that seems to me somewhat unlikely; and, even if correct, does not detract from the fact that Jingang material showed very significant variation: see para 181 above.

197. Sixthly, I am somewhat sceptical as to the picture painted of Sinochem's ignorance of Northchem – which appears to be a chemical import/export company based in Tianjin since 1991, with a website traceable on Google.

Information from Sinochem

198. It is, of course, for CSAV to prove its case. I must, however, record that it seem to me likely that Sinochem had or had access to information about the material shipped or other Jingang material which would have been informative. The disclosure given by Sinochem is very limited indeed. Mr Wang Fei told me that that was because the general company policy was to keep trading information and documents for no more than five years. Some documents nevertheless remained, having been obtained from shipping agents, via Sinochem's logistics department. This seems an unlikely explanation in respect of the contract of sale which was one of the documents disclosed.

199. On 6th December 1999 Dr Beeley met Mr Lu Ming at Sinochem's Tianjin offices. The meeting had been arranged through Norton Rose, the Owners' solicitors. Mr Ming is said by Mr Wang Fei to have been in a junior position. In a statement of 9th March 1998 Mr Lu Ming declares himself to be in a marketing section mainly responsible for importing rubber and steel. It is clear from Dr Beeley's contemporaneous note of the meeting and from his oral evidence that Mr Lu Ming knew a considerable amount about UN 1748. I do not regard it as credible that he did not inform his superiors of the meeting, particularly since, according to Dr Beeley's note, he appeared genuinely surprised to learn that the shipment had been involved in the casualty, and said that his colleagues had mentioned to him that there had been no problem with this particular shipment. He then stated that he would find out from his colleagues which factory was the manufacturer and revert (he did not do so despite several reminders).

200. In July 2001, well before the expiry of any five year period, CSAV's solicitor, Mr Morris, had a meeting at Sinochem's Tianjin offices with Mr Geng Xiao Yuan, a director/senior economist and a Sinochem lawyer. Its purpose was to invite Sinochem's assistance in the defence of the arbitration. Mr Geng declined such assistance for a number of reasons, one of which was (as recorded by Mr Craig Morris of Clifford Chance) that "*Sinochem does not keep records of their documents*". In August 2003 CSAV's solicitors wrote to Sinochem asking for assistance in the arbitration by providing access to files and evidence to show that the CH shipped was in good order and condition.

The letter indicated that, to the extent that Owners succeeded with their claims in the arbitration CSAV would be obliged to institute immediate proceedings against Sinochem to recover all its losses. It invited Sinochem to indicate whether it would be prepared to cooperate in commercial negotiations with the Owners "*in order to avoid future liability*". The letter asked for the name of Sinochem's liability underwriters. Dr Beeley had further meetings with Mr Lu Ming in 2004.

201. It was suggested to Mr Wang Fei (and denied by him) that there was a file of documents at Sinochem from which not all of the documents had been disclosed. Whether any such file still exists I cannot tell; but in the light of Mr Wang Fei's evidence there certainly once was further relevant documentation which has not been produced, despite the fact that Sinochem was aware in December 1999 what had happened on the "Aconcagua", and in August 2003 that a claim might be made against them. Whether Sinochem made inquiries of Jingang about the material shipped, and with what result, is not apparent. If, which seems to me unlikely, it did not do so, it certainly could have done. I cannot, however, tell what influence Sinochem might have been able to bring to bear on Jingang to provide information.

Is Donghai representative of the most thermally unstable 1748?

Sinochem's submissions

202. Sinochem submits that the answer is "No" for a number of reasons.

203. Firstly, Professor Gray found that it had a moisture content of only 0.21% - much less than the maximum 1% for which CSAV argues and markedly less than 5.5%. 0.21% is even less than what Dr Beeley was told when he visited the Donghai factory was the range of Donghai product. He was told that Donghai had a maximum of 3% moisture, and that it came in two ranges: 0.25% - 2.5% (for domestic use) and 0.25 – 1.5% (for export). He was also told that the normal range was 1.1% -2.95% max. (I infer that this referred to the totality of the product). Anything below 1% was regarded as a special or dangerous product by the manufacturer because of the risk of ignition because of its dryness.

204. Secondly, if, as I have held, a prudent carrier could anticipate receiving product of a moisture up to 5.5%, then CSAV has not established the range of characteristics of such a product. Sample A is inadequate for this purpose for a number of reasons:

(i) At 5.8% its water content exceeds 5.5%;

(ii) The water in it is not water of hydration (a fact which Professor Gray discovered when he subjected the sample to X-ray diffraction);

(iii) It originates, so Dr Beeley understood, from Southern China;

(iv) It came from store in Rotterdam and had probably deteriorated (hence the water content). Fresh samples tend to be less stable than old ones (see Clancy 1987 Table 5);

(v) It had fewer iron and magnesium particles than Zhenjiang or Donghai. If it had had a greater iron content it would almost certainly have had a lower CAT.

205. Thirdly, treating Donghai as the benchmark assumes that the Jingang material is to be treated as abnormal, without justification.

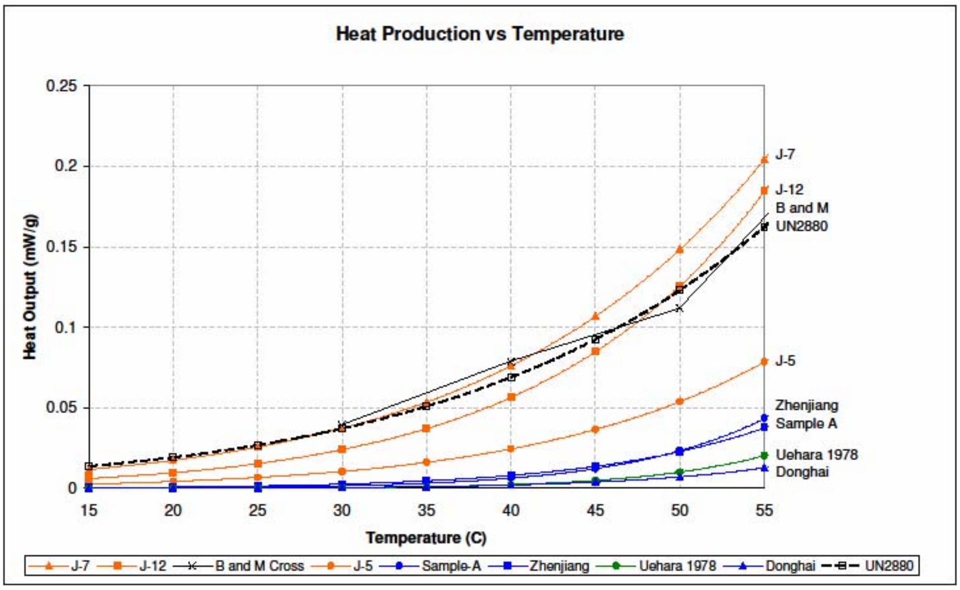
The Jingang material - discussion

206. The Jingang results show the extreme variability of the Jingang product. In order to determine whether the Jingang material actually shipped had abnormal characteristics it is necessary to consider two related questions:

(a) whether the Jingang material tested by Professor Gray (or some of it) had abnormal characteristics; and

(b) whether or not the Jingang material actually shipped had those abnormal characteristics or worse.

207. Professor Gray produced a graph which plots the heat output at increasing temperatures of the following samples; (a) Donghai; (b) J-12 (i.e. Jingang drum 12); (c) sample A; (d) J-7; and (e) the Uehara material. Mr Phillips produced a similar graph to which he has added the results for (f) J- 5; (g) Zhenjiang; (h) UN 2880; (h) B & M’s Sample X. On this graph (see below) the vertical axis is in milliwatts per gram and the horizontal in degrees centigrade.



208. As can be seen the materials divide into two groups. The bottom group consists of J-5, Zhenjiang, Sample A, Uehara, and Donghai with heat output at 50ºC between about 0.1 and 0.6 mW/g. although J-5 might be regarded as in an intermediate position. The upper group consists of J-7, J-12, B & M, and UN 2880, with results at the same temperature of between about 0.16 and 0.2 mW/g.

209. Sinochem contends that the chart shows no more than that heat output increases with increasing moisture. In the bottom group the moisture content contains J-5 (moisture content: 1%); Zhenjiang (0.30%); Sample A (5.8%); Uehara (≤1%); Donghai 0.21%). The upper group contains J-7 (2.6%); J-12 (3.5%); B & M; and UN 2880 (8%).

210. CSAV contends that the significance of these results is twofold. Firstly, the marked distinction between the lower and upper groups points to a degree of thermal instability markedly abnormal for UN 1748. J-7 and J-12 did not behave like any other UN 1748 material - even Sample A with its 5.8% water content, which may have been attributable to deterioration. By contrast the Uehara, Donghai and Zhenjiang material (and to a lesser extent the J-5 material) had a broadly similar thermal stability irrespective of moisture content.

211. Secondly, J-7 and J-12 did behave like, indeed worse than, UN 2880, the hydrated material, with a well known lower thermal stability and with a different hazard profile, history and chemical composition. That was the material involved in two catastrophic casualties – the "Contship France" and the "DG Harmony". Professor Gray explained that the readings for UN 2880 are for material which was from the same batch of material as had been on

board those two vessels. It was not, thus, in is view, normal 2880 (although it had been thought to be so). In 1995 PPG, the manufacturer had gone to a cheaper source of lime, called "*rotary lime*" which PPG stopped using after the casualties when they reverted to "normal" lime (see para 65 (xvi) above).[24]

212. I regard CSAV (in effect Prof Gray)'s analysis as sounder. The heat output results do not simply show that heat output increases with moisture content. It is noticeable that J-7, the material with the highest output has a lower moisture content than J-12, the second highest. Further UN 2880 and Sample A produced markedly different results although both have high moisture content. J-5 with 1% moisture has a higher reading than Sample A with 5.8%. Something other than moisture appears to be at work. What the results do show is as summarised in paragraph 210. The fact that the B& M material appears in the upper group does not establish that normal UN 1748 has characteristics which place it in that category. It is equally consistent with B & M having obtained a sample which behaved like the rogue UN 2880.

213. Prof Gray's figure 10 (see para 172 above) shows diagrammatically the plotting of his experimental results as straight lines consistently with classic F-K theory. He has also plotted, using the least squares methodology, the Donghai, Sample A and J-5, J-7 and J-12 material. The results are contained in Appendix 1.

214. As is apparent the Donghai and Sample A i.e. UN 1748 material lines run in parallel but with lower CATs as moisture increases. By contrast the J-12 and J-7 lines cross each other and the J lines run across the1748 lines. This shows that the Jingang material has activation energies and thermo-kinetic characteristics different to those of Donghai and Sample A and different from batch to batch in what is supposed to be the same material.

215. Mr Phillips replotted the results in a different way. Firstly, in his figure 4 (and subsequent variants) he joined up the marks representing the results on a dot-to-dot basis without using the least squares method. Secondly, he performed an exercise of plotting the Jingang results on the assumption that Professor Gray's results had a +/- 3% spread between subcritical and supercritical temperatures. Having thus established outer boundaries of where the CATs might lie he postulated straight lines within those boundaries which did not cross and which were in his view "*entirely plausible representations of the results as they are reported*": see Appendix 2 to his 4th Report. By contrast if the least squares method is used some of the lines do cross.

216. Professor Gray regarded this exercise as "*completely unorthodox non-science*". I agree that it is unorthodox and unscientific. It does not represent the manner in which plots are made in the combustion literature. Further the bracket spreads in Professor Gray's oven, which is the largest purpose built oven in the world with an experimental accuracy of +/- 0.3ºC, were different.

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[24] Mr Bright submitted that I should be cautious about accepting this material as rogue; but it seems to me likely that it was.

All the Jingang CATs were determined to a bracket spread of +/- 0.7ºC. These are very acceptable bounds.

217. For both of these reasons I do not derive much assistance from Mr Phillips' exercise. It provides little more than a rough indication of where a line *might* lie. I regard Professor Gray's approach (based on experimental data and recognised statistical technique) as more reliable for the purpose of predicting the CATs of bodies larger than those tested, identifying differences between materials and making meaningful comparisons.

218. The accuracy of any extrapolation will depend on the number of experimental results from which the extrapolation is derived. Professor Gray tested samples of four sizes for each of Jingang drums 5, 7, 12 and 42, namely 0.5, 1, 2 and 4 litres. That is a normal number of tests to use: see Beever *"Spontaneous combustion – isothermal test methods"* at section 4 (although Professor Gray refers in his report to the procedure being repeated until the CATs for 5 or 6 sample sizes are known: para 4.2; but in another passage to needing "*at least 3 or 4*": para 5.1.1).

219. Mr Phillips expressed the view that 3 or 4 sample sizes were sufficient to draw a straight line plot to ascertain the activation energy of a given material and to extrapolate to other sizes for that material; but that that number of samples was insufficient for the purpose of comparing the various straight line F-K plots of different materials. I had some difficulty in following this point. The purpose of the straight line plots (if that is what results from the experimental data) is to enable the inquirer to make extrapolations to larger material. This will be justified if sufficient experimental data has been obtained that bears out what F-K theory predicts namely that CATs decrease on a straight line basis with increasing size. If the samples are sufficient in number for the purpose of extrapolation in the case of a particular material it is difficult to see why they are insufficient for the purpose of comparing one straight line with anther.

220. Mr Phillips' answer, as I understood it, was that the straight line takes a path between plotted values which may lie either side of it and that, if lines derived from four experiments are used to make fine distinctions between one material and another the exercise may be misleading because results for one material outwith the line of best fit for it may be quite close to similar results outwith the line of best fit for the other material.

221. It seems to me, however, that if you have a sufficient number of results to describe an F-K straight line plot it is legitimate to compare one plot with another; and that the number of experiments, the accuracy of the measurement, and the range of sizes in Professor Gray's experiments are such that reliance can be placed on them for extrapolation and comparative purposes. It is a feature of Professor Gray's work that he has used quite large commercial samples (instead of traditional testing in small baskets) and temperatures lower than the range traditionally tested.

Discussion

222. In view of the fact that the Donghai material gave consistent and reproducible results which were congruent with the Uehara corrected results it is understandable that Professor Gray should have treated Donghai as the paradigm for UN1748, particularly since in his view UN 1748 would be regarded as limited to 1% moisture. I do not, however, accept that the Donghai results can be taken as representing the outer limit of the range of thermal stability for normal UN 1748. Donghai had a CAT of 77.6 º for cylindrical drums. UN 1748 itself indicated that the CAT at which decomposition might occur might be as low as 60ºC. Further the Donghai sample had a very low moisture content. Sinochem has no positive case as to what different CAT there would have been if its moisture content was 1% but the results from the wetter Sample A do not suggest that they would have been markedly different. As I have decided, the prudent carrier could expect a moisture content of up to just below 5.5%.

223. I do not, however, accept that it is impossible for the Court to reach any conclusion as to the normal characteristics of UN1748 with moisture up to 5.5%. Specifically, I regard Sample A as giving a reasonable indication of the characteristics of UN 1748 with such a moisture content. Sample A was, in chemical composition, in "dry" form. It had undergone some deterioration but it had an activation energy derived from the F-K plots (12581 +/- 452) similar to Donghai (12507 +/- 375). Its F-K plot was almost precisely parallel to other UN 1748 material. In other words the materials behaved in the same way, allowing for the difference in moisture content. Lastly its heat output curve corresponded closely to that of Donghai, Uehara and Zhenjiang materials. It had a CAT in excess of 60ºC.

224. I also regard the heat output curves set out in para 207 and the F-K lines referred to in para 213 above as giving a useful insight into the normal characteristics of UN 1748. In the former the lower group, particularly the bottom 4, displays a range of similar outputs whereas the upper group has outputs markedly greater and consistent with the rogue UN 2880 on the "Contship France" and the "DG Harmony". In the latter the F-K lines of the Jingang material, properly plotted, show that the Jingang material has activation energies which differ from the Donghai, Sample A, Uehara and Zhenjiang material and that it behaves in a different way (such that the Jingang lines cross the lines of the other material – which is not a result to be expected if the only material difference between Jingang and other material was water content). The results also differ markedly as between samples of supposedly the same material. This suggests that the Jingang factory may produce rogue material. Such a conclusion derives some support from evidence which suggests that there were problems with quality control at the Jingang factory.

The Jingang factory

225. There is no first hand evidence of conditions and quality control at the Jingang factory in autumn 1998. In February 2002 representatives of the Huatai

Insurance Agency in Tianjin visited the factory and were refused entry. They then arranged for a chemical expert who had previously worked for the China Inspection and Quarantine Bureau ("CIQ") and/or the China Commodity Inspection Bureau ("CCIB") to investigate. He reported in the form of brief written answers to a questionnaire composed by Dr Beeley. Who the investigator spoke to is unknown. The investigator himself is unknown since he refused to sign the answers or identify himself.

226. As a result of his inquiries, he reported (i) that the product was manufactured by a stainless steel plant; (ii) that "*the analysis report was not available for reference*"; but (iii) that according to a CIQ surveyor (unidentified) the assay results "*were in accordance with the standard of cargo for export*". In response to a request for details of quality control procedures together with tests or analyses carried out on the batches the response was that there were analyses with the titration method, every 12 drums counting as one batch. This is a reference to testing for available chlorine. There is no evidence of batch testing of raw materials: which is important for quality control purposes to detect contamination: see pages 5 and 6 of the joint report. Problems with raw materials underlay the "Contship France" and "DG Harmony" casualties. The report also revealed that the normal variation in the results for the product was 30 ppm and that no rejection of material by quality control had occurred about the time when the "Aconcagua" batches were manufactured. Nor were any plant failures logged at the time. No problems had been encountered with product decomposing in storage. Lastly the report stated that the product had been conveyed to the dock by truck where it had been stuffed by the stevedores under Customs supervision. Mr Wang Fei's evidence was that it was stuffed at the factory. No records from Jingang have been produced.

227. In March 2004 Dr Beeley visited the Jingang factory, which had by then ceased production, and took some photos from outside the perimeter. These present a sorry sight but they do not show the state of the factory in 1998.

228. In April 2004 Dr Beeley visited and took pictures of the Donghai factory. These show part of the factory to be in good condition, but other parts show evidence of poor housekeeping and deterioration of plant. Dr Beeley was told that the Jingang plant was small and had a very poor reputation; that it had gone bankrupt, that there had been lots of problems and lots of complaints (by customers of Donghai to Donghai about Jingang) and claims from customers over the quality of its product; and that in the previous year the factory had shipped 2 containers of CH which had been transhipped in Busan, Korea, where the cargo had *"smoked"* on the quayside whilst awaiting transhipment.

229. I accept that this third (or further) hand evidence from a competitor must be treated with caution particularly when Mr Wang Fei's evidence is that the Jingang factory did not go bankrupt but continued to trade from different premises following a change of ownership and restructuring coordinated by the local township; and when Mr Lu Ming said that he was unaware of any incidents arising in the manufacture or transportation of UN 1748 within China.

230. Significantly variable moisture content[25], observable particulate contamination and widely varying thermal stability characteristics (demonstrated by the time-to-ignition results) are, particularly in combination, indicators of poor quality control. Poor quality control may mean that problems in relation to the raw material are not picked up and that product will be produced not only with differing thermal characteristics but with unusual and unacceptable deviations from the norm. Evidence of poor quality control together with widely varying thermal stability results supports the inference that Jingang material was liable to produce, from time to time, a rogue batch of unusually low thermal stability.

Summary The characteristics of normal UN 1748

231. I would define the characteristics of normal UN 1748 of which a prudent carrier ought in December 1998 to have had knowledge, as being that it was capable of decomposing by self-heating at ambient temperatures as low as 60ºC; but that it was safe to carry in containers on or under deck (where it should be stowed away from sources of heat) in the temperatures normally experienced on containerships, its hazard history being as summarised in para 66 above. Those characteristics are consistent with the results for the lower group of materials referred to in para 207, but not for all the Jingang material. A prudent carrier would not have known that it was liable to self-heat at 40ºC or below. Nor would he have known that he should qualify the figure of 60ºC so as to produce some lesser figure for product stored in kegs in containers, let alone a figure as low as 40ºC.

The characteristics of what was shipped?

232. The next question is whether the material actually shipped had abnormal characteristics which posed risks of a wholly different kind from normal UN 1748. Since there is no direct information as to what was actually shipped other than that it came from the Jingang factory it is necessary to determine its characteristics by reference to what occurred on the voyage. The Jingang samples subsequently obtained provide insight into the quality control of the Jingang factory but they do not establish the attributes of the material shipped on the "Aconcagua" in December 1998.

233. If normal UN 1748 would have withstood the temperature regime in the No 3 hold of the "Aconcagua" on her December 1998 voyage, then the fact of the explosion would itself indicate that the material shipped had such abnormal characteristics. It is therefore necessary to determine what heating of No 3 FFOTS took place, and what the effect of that was.

What bunker heating took place?

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[25] If in the same batch. Mr Charlton suggested that the Jingang material might have come from different batches. M Lu Ming's evidence to Dr Beeley that the factory did not stockpile material but sent it straight out does not make that seem likely.

234. The vessel took on bunkers at Busan which were loaded into a number of bunker storage tanks including No 3 FFOTS. On 20th December she took on c 1,200 mt at Los Angeles which went into No 2 FOTS, Nos 3 AFOT (P & S) and No 4 FOT (P & S). The vessel began to heat bunkers in No 3 FFOTS at some time before 0900 on 23rd December when fuel was first drawn from that tank.

235. The bunker (storage) tanks on the Aconcagua were not fitted with remote read-out thermometers. When a bunker tank was being used, fuel would be drawn off twice a day from the storage tank(s) into a settling tank in the engine room. When that happened a sample would be drained from the drain cock located at the transfer pump in the engine room and its temperature measured. That result would be written with a red marker pen on the level gauge for the relevant tank.

236. When the crew abandoned ship there remained on the gauge for No 3 FFOTP the words "*HTG t =* ***53.0*** *CONS*" and for No 3 FFOTS "*HTG t =* ***63.3*** *CONS*". "CONS" stands for "Consumption". Dr Beeley's photograph (C2/1/117) of the gauges, taken after the fire, shows signs of the temperature figures having been previously rubbed out.

237. The arbitrators had before them written statements from, inter alios, the Master (Captain Horber) – taken in March 1999; the Chief Officer (Mr Dieckmann) – dated 12th March 1999; the Chief Engineer (Mr Gruener) – also dated 12th March 1999; the First Assistant Engineer (Mr Muzones**) –** dated 24th June 2002; the Third Engineer (Mr Obst) – dated 6th January 1999; an Electrician (Mr Bagay) dated 9th January 1999; and the Second Officer (Mr Horwege). Mr Gruener attended the arbitration and was cross-examined, as were the Master and the Chief Officer. A Civil Evidence Act notice was served in respect of all these witnesses.

238. Each side has criticised the other for its approach to the evidence of these witnesses. Sinochem complains that no attempt was made to bring any of them to give evidence and contends that, as a result, the value of their evidence is much reduced. CSAV says that it would have been very difficult to secure the attendance of witnesses who were employees of the Owners, with whom CSAV had been in acrimonious dispute. Further, since no notice was served by Sinochem under CPR 33.4(1) seeking permission to call these witnesses for them to be cross examined, CSAV assumed that their evidence was not challenged. At the lowest, it lies ill in Sinochem's mouth to complain of their non-attendance.

239. I do not propose to approach this evidence on the basis that the conduct of either party means that it should be looked at with circumspection; but to examine it to see what can properly be found from it despite the fact that it has not been, or not been further, cross examined. I do not regard the fact that no notice was served by Sinochem under CPR 33.4 (1) as an acceptance or deemed acceptance of the contents of the statements.

Beginning of bunker heating – 21st or 22nd?

240. The arbitrators concluded that the steam heating to the tank was applied for the first time during the morning of 22nd December 1998, 24 hours before the bunkers in the tank were first used at 0900 on 23rd December. I make the same finding – not because the arbitrators have done so (although that confirms me in my view) but because that is what seems to me highly likely.

241. The evidence of Mr Gruener, the Chief Engineer, was that heating was applied to a new storage tank about one day before it was required, although, as Mr Muzones said (para 9) in warmer waters it might be possible to heat up some of the tanks sufficiently for transfer within 12 hours. There seems to me to be no operational reason why it would be necessary, or why anyone would want, to start heating any earlier than 24 hours before consumption on 23rd December, particularly as ambient temperatures were moderate at the time.

The "x" marks

242. The documents before the court include a photocopy (made at some unknown date) of the engine logs. In the relevant logs there are, between 20th December when the vessel was at Los Angeles and 28th December, "x" marks against certain tanks. Sinochem suggests that these marks indicate when tank heating was being carried out. The "x" marks do not appear elsewhere in the log when bunkers were being heated e.g. in respect of the Nos 2 FOT (P & S) and No 3 AFOT (P & S) on the way to Los Angeles. The marks are thus unlikely to represent a contemporaneous record of heating (there was no change of crew which might have meant a change of practice). Mr Muzones could not recall having seen the marks in the original of the log when he was on board[26].

243. It is difficult to accept that the "x"s accurately reflect heating for two reasons:

(a) No. 2 FOTP was being *used* at 0830 on 20th December and would therefore have required to have been heated on 19th in accordance with the 24 hour heating practice being adopted on the ship: but there is no "x" for 19th December or any earlier day;

(b) if "x" signifies heating, then No 3 FFOTP and No FFOTS were being heated on and from 20th December, some 72 hours before use and when the vessel was in port. In respect of the period before Los Angeles No 2 FOT (P & S) and No 3 AFOT (P & S) and No 4 FOT (P & S) were being used but there is no "x" against any of them.

The significance of the "63.3" C notation

244. The evidence of the ship's personnel of how, when and why the temperature was measured included evidence to the following effect:

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[26] He suspected that the marks were made by the Chief Engineer on the ground that it was only he who calculated the quantities. If, as his evidence suggests, the marks were not there when he was onboard the vessel the suspicion does not seem to me well founded.

i Bunkers were transferred from the bunker tanks to the settling tanks twice a day, once in the morning and once in the evening: Mr Muzones, para 5. At each transfer the temperature of the oil was measured, usually by Mr Muzones, but occasionally by an oiler, at least a few minutes (according to him) after the commencement of the transfer (to allow for the sample to be representative of the bulk). According to the Chief Engineer the taking of the temperature would normally be well after transfer had commenced: para 16;

ii The temperature taken at each transfer would usually be reported to the Chief Engineer by the First Engineer or the oiler writing it on the glass of the remote tank gauge; Muzones paragraph 7; Gruener, para 21; although if the Chief Engineer was around the First Engineer would report it to him directly: Muzones, ibid.

iii The purpose of taking the temperature was to decide when to shut off the steam valves to the bunker tank and to give the Chief Engineer the necessary information to make a volumetric calculation for the purpose of calculating the fuel oil on board: this was done by the Chief Engineer at noon each day: Gruener, paras 21-22.

iv When interviewed in 2002 Mr Muzones could not recall having written the temperatures on the evening of 29th December 1998 prior to the explosion but confirmed that it would normally have been him who recorded the temperatures in that way: para 13.

245. The evidence given by the ship's engine room personnel as to the practice of bunker heating was fairly summarised by CSAV as follows:

i. Heating was applied to a bunker tank about 24 hours before the fuel was to be drawn: see para 241 above;

ii. For the initial heating of the bunker tank, the steam inlet valve for the heating coils would be opened fully: Gruener, paragraph 17.

iii. During the first transfer from the new tank the temperature would be measured *"and if it is at a sufficiently high enough temperature to facilitate transfer, then the steam inlet valve is "closed to less than one turn open"*: Gruener, ibid. The valves themselves may be seen on Dr Beeley's photograph 48.

iv. The fuel oil in No. 3 FFOTS needed only to be heated in that tank so as to allow it to be pumped to the settling tank: the aim of the operation was to reduce the viscosity of the oil sufficiently so that it could be transferred by pump to the engine room settling tank: Gruener, paragraphs 15 and 17.

v. The fuel oil in No. 3 FFOTS bunkered at Busan on 27th November 2008 had a recommended transfer temperature of only 35°C as reported in DNV's bunker analysis and operational pumping advice. It therefore needed to be heated only to this temperature to allow it to be transferred without difficulty. Accordingly the first transfer would be affected at whatever temperature the oil then was (Mr Gruener thought 45°C an appropriate figure after one day) on its way up to the temperature range at which it was to be kept.

vi. Mr Gruener's settled practice based on twenty years experience was to aim for a transfer temperature in the storage tank of between 50-60°C: Gruener, para 17; see, also, Muzones, paragraph 8**.** He tried to achieve the middle of the range.

vii. Although it was common practice on some vessels to leave the heating coils in bunker tanks fully open until the tank was empty, this was not the practice adopted by the Chief Engineer; the steam was adjusted as necessary in the light of the temperatures being recorded at each transfer: Gruener, paras 18 and 21.

viii. The temperatures of the tanks under consumption were taken at the morning transfer and at the evening transfer by Mr Muzones (but sometimes by an oiler): see para 244 above.

ix. The temperature was measured at the transfer pump in the engine room using a digital thermometer: Gruener, para 16.

x. The throttling of the steam valve, which was the responsibility of the 1st Engineer was a continuous process of adjustment of the tank temperature as required during the period the bunkers in the tank were being consumed: *"But when you measure the first day – for example, it is 45°C after one day, full open, then you let it one turn open. If it is already 50°C, then you close it down one third*[27]*. This is some experience and he is also an experienced First Engineer":* Gruener xx – [B1/112];

xi. Mr Muzones' evidence was to the same effect: *"When starting to heat a new storage tank, both the feed and return valves would be fully open. However if on the first transfer the oil temperature was at a suitable temperature then I would shut the inlet valve to just cracked open, which was about ¼ turn of a turn from fully closed. To do this I would fully close the inlet valve and then open it ¼ turn. This would usually be enough to maintain the temperature of the oil tank in the storage tank for transfer":* para 10.

xii. If the temperature of the oil fell back, then the steam inlet would be opened to give a "kick" up to the next tank transfer: *"I would tend to leave the inlet valve cracked open at about ¼ a turn until the tank was only a ⅓ full. If the temperature subsequently became too low for transfer then I would know because the transfer pump would become noisy. This would be an indication to me to heat the tank a bit more by opening the steam inlet valve to ½ or ¾ a turn open until the next transfer":* Muzones, para 11.

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[27] i.e. to about 1/3rd open.

xiii. *"As the contents of the storage tank reduce, we eventually shut off the steam to the heating coils completely. Based on experience, this takes place when the level has reduced to approximately one third full"* Gruener, paragraph 20.

246. On the basis of that evidence CSAV submits that it is likely that the oil in both of the No 3 Forward Fuel Oil tanks was heated to get it to within the 50-60ºC range mentioned by Mr Gruener and that it was then nursed at a temperature of a little in excess of 50ºC and up to 55ºC by throttling of the valves. Mr Gruener's evidence was that he always tried to achieve the middle of the range, and that, if the First Engineer told him that the temperature was at or approaching the top of the range or above it, he would ask for confirmation that the steam bar was closed. The evidence of Mr Muzones was that it was his practice to achieve a minimum of 50ºC and a maximum of 60ºC or below. Mr Obst recalled that the required temperature for transfer was about 50ºC. Accordingly, so CSAV submits, if the temperature was measured at 63ºC on transfer, the valve would have been closed completely as Mr Muzones said in terms (para 14) and Mr Gruener confirmed (para 25). When Mr Gruener returned to the vessel after the casualty he found the inlet valves for the No 3 (P & S) FFOTs already closed. For that reason he thought that the 63.3ºC could not represent the 29th December morning temperature.

247. CSAV submits that the best evidence of the likely temperature of the No 3 FFOTS from the time it reached 50ºC is the 53ºC figure for its sister tank. There would have been no reason to maintain one tank ten degrees higher than the other, especially if the higher temperature exceeded 60ºC. The likelihood is that both tanks were heated to 50-55ºC; and that if they edged above 55ºC they would be brought down; No 3 FFOTS probably reached 63ºC on the evening of 29th December either because the steam valve had been cracked open during the morning transfer somewhat too much or because the temperature was too cold in the morning, having fallen below 50ºC and required a kick to bring it up to within the range by cracking the valve open a full turn, which, given the warmer sea conditions, pushed the temperature up over the period leading to the evening transfer to above 60ºC.

248. Sinochem submits that the state of the evidence and the number of possibilities is such that the Court cannot properly make any finding as to what the heating regime was. The scenario propounded by CSAV is implausible. Only the First Engineer could give first hand evidence of the heating actually applied; the Chief Engineer could only say what ought to have happened if his instructions had been followed. Further, the evidence of all three was based simply on common procedure; and was given when Owners were being accused of negligence in heating the bunkers to temperatures in excess of 65ºC.

249. I do not regard the evidence of the engine room staff as invalidated by these criticisms. Their evidence concerned a routine marine operation. They would have followed a standard procedure, which could be expected to have been laid down and monitored by the Chief Engineer and implemented by the First Engineer, who were in regular contact with each other each day. I note that

the sort of practice of heating adopted by the Chief Engineer was accepted by the arbitrators as commonplace at sea and neither unreasonable nor negligent. I see no reason to think that the Chief Engineer, when speaking of his practice of 20 years, was slanting the evidence in Owners' favour.

My conclusions on bunker heating

250. In the light of this evidence, which I regard as credible, it seems to me that the oil temperature history will have been in three stages. In the first stage after bunker heating was first applied the temperature of the oil would increase from its unheated base (circa 15ºC, the surrounding sea temperature on 22nd December) until it reached the "Gruener" range of 50-60ºC. When exactly it did that is unknown; but it seems to me likely that after 24 hours with the valve fully open (it has more than one 360º turn) i.e. by 0900 on 23rd December it would have reached about 45ºC (see the evidence of the Chief Engineer).

251. In the second stage it would reach the 50-60ºC range, where the staff would seek to maintain it in or around the middle of that range by monitoring the temperature every 12 hours. The evidence of Mr Manzones, whose primary task it was and of the Chief Engineer was to similar effect. I regard this evidence as entirely credible. It represents a sensible and practical approach.

252. I have not ignored the fact that different accounts may be found in the evidence as to the setting to which the valves would usually be adjusted in order to maintain the temperature within the desired range (e.g. to $^{1}/_{3}{}^{rd}$ or ¼ turn open, or according to Dr Beeley's note of his interview with the Chief Engineer, to one turn, which was not the Chief Engineer's evidence) or in order to increases it to the desired range ($^{1}/_{2}$ or $^{3}/_{4}$ turn).Whilst there is obviously a difference between $^{1}/_{2},$ $^{1}/_{3}{}^{rd}$ and ¼ it is not in practice that easy to distinguish the setting (the valve is not calibrated and may even have some slack), I do not regard the fact that different fractions have been referred to from time to time as invalidating the conclusion that the valves were adjusted to whatever fractional aperture was required in order to maintain the temperature within the desired range. The evidence given by the Chief Engineer in his written statement and under cross examination seems to me more reliable than what is recorded in Dr Beeley's note.

253. The alternative – that the temperature was not monitored at all or that, if it was, the engineering staff did not adjust the heating so as to try keep the temperature in the "Gruener range", even though less heat would be required as the amount of oil in the tank reduced, seems to me implausible, and unlikely to have been adopted by the First, and left unchecked by the Chief, Engineer – contrary to their evidence. I do not regard it as at all likely that the temperature of 63.3ºC was recorded once and then maintained at or about that figure for several days. That would conflict with all the evidence and would provide no explanation as to why one tank was run at 10º hotter than the other. I regard it as equally unlikely that the tank was run for the most part at a temperature in excess of 63.3ºC and only brought down on the last day.

254. The temperatures set out on the gauges are likely to represent the temperature measured on the last fuel transfer for each tank. That leaves the question whether they represent the morning or the afternoon temperature for 29th December. In my view the 63.3ºC reading is likely to have been the afternoon reading on 29th December, recorded for the Chief Engineer to see the next morning when he made his noon day calculations. If 63.3ºC had been the morning figure the valve would have been adjusted and another (lesser) reading taken in the afternoon. The Chief Engineer's evidence was that the first time he was aware of this tank being heated to 63.3ºC was when he went back to the ship after the fire.

255. I am fortified in that conclusion by the fact that on 24th January 1999 Dr Beeley had a discussion with the Chief Engineer in the absence of the Owners' solicitor. His note of that conversation includes the following:

> *"The temperatures written on the gauges are the last temperatures to be recorded about 8-10 hours prior to the fire."*

That note ties in with the entry in the log for 29th/30th December:

" 1630H Transfer HFO # 3 FFOTP/FFOTS TO SETT'L TK 24 M³ "

(There is a similar entry at 1700 on 27/28th).

256. It is apparent from these two items that the last drawing on 29th December was at 1630 and from both tanks, in which case it would have been necessary to take the temperature for both tanks.

257. In the third stage steam would have been turned off. Mr Gruener explained that, as the contents of the storage tank reduced, steam would eventually be shut off to the heating coils completely. He said that this usually took place when the level has reduced to approximately one third full. In the present case that is likely to have occurred after the second transfer on 29thDecember.

258. What had caused the temperature in the starboard tank to rise to 63.3º C is unknown. But it is likely to have been for one or other of the reasons suggested by CSAV.

The effect of the heating actually carried out on the container at 15-09-06

The simulation voyage

259. In December 1999 the "Aconcagua", now renamed "CSAV Shanghai", carried out a voyage along essentially the same route. The opportunity was taken to place a container in position 15-09-06. Probes were installed at various places on the tank walls surrounding 15-09-06, the faces of the container which faced the tank (front end, outboard facing side, and bottom), and those which did not (aft end, inboard facing side and top); and at level 10 on the walkway in holds 2 and 3. Measurements were taken of the temperature recorded by these

probes and also of the oil on transfer, as well as of the air and sea temperatures.

260. There were certain differences between the two voyages. For operational reasons the heating on the "CSAV Shanghai" had to be begun earlier than on the "Aconcagua". On the "Aconcagua" heating began, as I have found, on 22nd December 1998, after her departure from Los Angeles, with first consumption on 23rd December, and continued for eight days before explosion in the early hours of 30th December. On the "CSAV Shanghai" heating began on 18th December whilst the vessel was on passage across the Pacific, with consumption starting on 21st December. The sea and air temperatures prevailing in respect of the "CSAV Shanghai" were lower than those prevailing for the "Aconcagua" for the equivalent position. The sea temperatures at the outset of bunker heating were similar.

261. The plan for the heating of the "CSAV Shanghai" was as follows: (a) to heat No. 3 FFOTS for 24 hours leaving the steam inlet valve supplying the heating coils fully open; (b) thereafter to leave the valve ¾ of a turn open; (c) to adjust the valve as necessary so as to attain a spot temperature of as close to 63.3°C as possible and, if necessary, to prevent it exceeding 63.3°C.

262. There is a dispute as to whether this plan was adopted (a) because it was believed that a continuous temperature of 63.3ºC was the likely temperature regime on the "Aconcagua"; or (b) in order to investigate, as a worst case analysis, the effect of an upper bound of a 63.3ºC oil temperature (in a tank which was being depleted by consumption) on a container at 15-09-06. I am satisfied, having heard Dr Beeley, that it was the latter.

263. After the first 24 hours the valve was left ¾ of a turn open. The transfer temperature of the oil reached 63°C after 7 days on 23rd December[28]. On 24th December it increased to 68°C whereupon the valve was closed to ½ a turn open in order to bring it down. On 25th December the temperature was 66ºC and the valve was turned down to ¼ open. On 27th December, the day equivalent to the explosion on the "Aconcagua" the temperature was 61ºC and the valve was turned up to ½ open. On 28th December the temperature climbed to 66ºC and on 29th to 76ºC when the valve was closed down to ¼ open.

264. The experiment thus modelled the oil being heated (during the period expiring on the date equivalent to the "Aconcagua" explosion date i.e. 27th December 1999) to over 60°C and maintained thereafter for five days continuously: 60 - 63° C for three days; 68 °C and 66°C for one: see C2/123.

265. The experiment revealed the following information:

(a) the tank wall and container face temperatures increased with increasing oil temperatures in a broadly linear relationship;

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[28] 7 days because there were two 18th Decembers, the vessel crossing the international date line

(b) the *tank wall* temperatures were always less than the *oil* temperatures; and the *container face* temperatures facing the heated walls were always less than the tank wall temperatures; and over 10º less when the tank was at its hottest. The faces of the container not facing the tank walls were much less affected. The top of the container was cooler than the container bottom and the aft face was scarcely affected at all.

(c) the *container wall* temperature varied widely between one face and another. The range (from hottest to coolest) was, broadly, front end of container, outside, and then bottom. The highest temperatures attained from the manual log with the oil temperature at 61ºC [in the case of the outboard side] or 63ºC for the others were respectively: front end 43.7ºC [29]; side 40ºC; bottom 39ºC [30]. The highest reading ever recorded with heating at temperatures higher than 63ºC (68ºC; 66ºC) was 44.7ºC for the container foot pad outboard aft;

(d) Bunkers were drawn off twice daily. Each drawing reduces the level in the tank sharply so that (for instance) the oil falls from a level above the position of the container to one below it within three days. The effect is that the front and outboard side of the container were exposed to full radiant heating for only 2.3 days on the "Aconcagua". After that the level of the "radiator" formed by the tank walls surrounding those two sides dropped over a 3 day period. The oil then dropped below the level of the bottom of the container. The bottom of the container will, therefore, have "sat" on the heated oil tank for some 5 days or thereabouts (depending on the trim of the vessel); but the container had a 30mm thick wooden or ply board floor, which is a poor heat conductor. The effect is shown in figure 8 of Dr Beeley's report of August 2008 where the second and third topmost lines (the aft and inboard faces of the tank) drop abruptly after "Day 15" and the top line (the tank top i.e. the wall of the tank facing the bottom of the container) remains heated for longest, being the last part of the tank wall facing 15-09-06 to be left by the falling oil level, although the container temperature in way of it (at the container floor) is increasingly left behind – at up to 20ºC less.

266. CSAV submits that the modelling carried out on the "CSAV Shanghai" casts light on the temperature to which the container will have been exposed on the "Aconcagua". The highest container temperature of about 45ºC produced by heating the bunkers to 66 - 68ºC represented a difference of some 20ºC. If the oil temperature on the "Aconcagua" was kept at around 55ºC, save for an overshoot on the last day, then the corresponding highest container temperature in way of 15-09-06 would have been about 35ºC save for a short

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[29] There is a higher datalogger reading of 44.1 or 44.2 for the first two hourly readings of 23rd December.

[30] There are 6 datalogger readings on 24th December between 39.2 and 39.5.

period. The oil temperature spike of 63.3ºC reached between the morning and afternoon on 29th December would have been a spike with no perceptible effect on the container, particularly having regard to the fact that by then the level of the oil was well below all relevant tank wall faces facing the container. The oil had dropped below the level of the tank top on 25th December.

267. If that analysis is correct then it would follow that the CAT of the cargo shipped on the "Aconcagua" was probably below 35ºC, as, in my judgment, it was.

268. It is common ground that the Donghai material is extremely stable and would not have exploded if subjected to the maximum wall temperature profile measured by Dr Beeley in the course of the CSAV Shanghai survey. It is also unlikely that such material would have exploded even if the temperature in the oil tank had been 63.3ºC, the highest recorded transfer temperature on the Aconcagua, for nine days. The same applies to Zhenjiang and Sample A.

Ambient temperatures elsewhere in Hold No 3 and other holds

269. In determining (a) the temperature likely to have been experienced by the container on the "Aconcagua" and (b) the causative impact, if any, of the heating of No 3 FFOTS it is necessary to consider the ambient temperatures likely to have been experienced by the container if it had been stowed elsewhere in No 3 hold (or in another hold) away from the source of heat presented by that bunker tank.

270. The experts agree that the factors which can influence the temperature of the cargo after loading on board the vessel include the following: (a) the outside air and sea temperatures; (b) the temperature of No. 3 FFOTS and the heating or bunkering of it; (c) heating or bunkering of other fuel oil tanks in the No. 3 hold; (d) the intensity of sunlight incident upon the external structure of the vessel and the period for which it was exposed to sunlight; (e) heat from other holds; (f) the effect of ventilation; and (g) the effect of adjacent containers. They also agree that the air temperature in the hold and the temperature that the containers stowed away from position 15-09-06 would experience, would also be affected by these factors.

No 3 hold unheated

271. On the "CSAV Shanghai" air temperature measurements were taken in Hold No 2, which was not bounded by any bunker tanks. Dr Beeley's evidence was that the measurements taken by the Chief Engineer in Hold 2 during the "CSAV Shanghai" exercise indicated that the air in the upper part of the hold on the "Aconcagua" would, unheated, have attained 30ºC for about six days. The measurements upon which he relied were four hold measurements taken between 4th and 7th January 2001 (when the vessel was at or below Balboa), in No 2 hold at level 10 of 29ºC, 29.5ºC, 27.5ºC and 24.5ºC respectively. The sea and air temperatures in respect of the "Aconcagua" were greater than in respect of the "CSAV Shanghai" so that an unheated hold on the "Aconcagua"

would have had, CSAV submits, temperatures somewhat over 30ºC. In my judgment the *unheated* air temperature in No 3 hold is likely to have been somewhat over 30ºC in the hottest days of the voyage in the upper reaches of the hold, which for this purpose certainly include levels 10 and 12 but probably extend to levels 6 and 8.

The effect of bounding bunker tanks

272. All of the tanks bounding No 3 hold had either been bunkered on 20th December at Los Angeles (with fuel oil bunkered at 48ºC) or were under consumption or being heated up to the "Gruener range" at around 55ºC. Thus:

(a) the aft part of the hold would have been warmed by the effect of bunkering both the No 3 AFOT (P & S) at Los Angeles on 20th December 1998;

(b) the forward athwartships wall containing No 2 FOT (P & S) would have been warmed by:

(i) the heating of the No 2 FOTP which had been on consumption before Los Angeles and continued to be consumed until 22nd December;

(ii) the bunkering of the No 2 FOTS at Los Angeles;

(c) the forward part of the hold would have been warmed by the heating of Nos 3 FFOT (P & S) which began on 22nd December and remained under consumption for the next 8 days.

Ventilation

273. Dr Beeley found, in his investigations in January and February 1999, that the natural ventilators at the forward end of the hold were open at the time of the explosion. He was unable to inspect the aft ventilators. The natural ventilators are situated on an enclosed section of the weather deck below the passage ways serving the container deck storage area on the hatch covers under a grille which leads down to the enclosed space. The ventilator was a downward facing mushroom ventilator angled toward the deck. There was no through-flow of air during passage and the ventilators were a source of only minimal ventilation in the hold.

Conclusions to be drawn from the "CSAV" simulation

274. In the light of the CSAV simulation Dr Beeley concluded that the amount by which the *heated* hold air temperature in the Aconcagua would have exceeded the *unheated* hold air temperature would have been between 5- 10º C depending upon position, the temperatures being hotter in the upper reaches of the hold. He plotted the resulting heated hold air temperature on his figure A 11. This figure shows a temperature plateau of around 23ºC between days 6

and 14, followed by a dip; the temperature then climbs from about18ºC on day 26 to about 32.5ºC on day 28 where it stays until Day 34.

275. This temperature profile, which became described as the "*away from*" temperature, is said by Dr Beeley to represent the temperature in the upper region of hold No 3, which he explained as meaning level 6 (the level of the container) and above. He described this, in my view accurately, as representing a *conservative* assessment of the effect of the general bunker heating upon the temperature in hold no. 3 after Los Angeles. In his view temperatures in the upper region of the hold could have reached the high 30s over a 6 day period.

276. His assessment is based on or supported by the following:

(a) The "CSAV Shanghai" simulation: even in the colder sea and air temperatures which prevailed the hold temperatures in hold no. 3 at level 10 were some 5-7°C higher than the temperatures in unheated hold no. 2 at the same level: see Figure A2 [C6/184] comparing Probe D/hold 2 (brown dot) with Probe C/hold 3 (mauve x). See also Mr Phillips' plot at C7/26.

(b) In connection with the "Contship France" Dr Holleyhead of Burgoynes, working in tandem with Professor Gray's investigation into the thermal properties of UN 2880, carried out an extensive programme of experiments similar to those carried out on the "CSAV Shanghai". He reported that in large consignments of thermally sensitive materials: "*temperatures in a box-ship [sc. container ship] hold can easily reach the upper 30°C range especially in tropical waters*".

(c) Some steady state CFD[31] modelling was carried out by Dr Alan Rose in respect of No 3 hold on the assumption of a temperature differential between level 2 and level 12 of only 5º viz 27.5º and 32.5º C. This conservative assumption showed temperatures in the mid to low 30s in some areas without taking into account (a) the effect of the heating of No. 3FFOTP (the sister tank), (b) the heating of or presence of warm/hot oil in other bunker tanks around hold no. 3 and (c) radiation.

277. The upshot of Dr Beeley's analysis is that, even an *unheated* hold would have probably generated temperatures of 30ºC and above in levels 6 and above. The effect of the other tanks surrounding No 3 hold having been either freshly bunkered at Los Angeles or having been under consumption up to 23rd December, would have been that, even if Nos 3 FFOT (P & S) had not been heated, the hold temperature in level 6 and above would have been higher than in an unheated hold. I accept that the figure is likely to have been around the

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[31] Computational Fluid Dynamics. It is necessary to treat this model with some caution. It represents a snapshot in time. It takes no account of radiation (and as a result underestimate temperatures of container surfaces facing the tank walls); and it assumes a void at the bottom of hold No 3 as opposed to a general cargo.

mid 30ºs. These figures are to be compared with the peak perturbation of 35ºC (see para 266 above) to which, save for the spike resulting from the bunkers being heated to 63.3ºC, the container was, in all probability, in fact subjected.

278. In addition it is necessary to take account of the fact that all materials experience thermal inertia to differing degrees. There will be a time lag, which may be lengthy, before they respond to any temperature change. As a result a large but short lived increase in temperature may have practically no effect so far as causing self-heating is concerned. What is of importance on a voyage is not the diurnal variation but the mean temperature. The perturbation caused by a particular variation in ambient temperature is very much dependent on the nature of the body itself and is determined by (a) the duration of the variation, (b) the response time of the body and (c) the degree of stability of the material itself.

279. The perturbation created by taking No 3 FFOTS to a spike of 63.3ºC would be limited compared with the effect of days of exposure to the peaks of the "away from" regime. The contrast is shown diagrammatically in Mr Phillips' Figure at C8/108 in which the dotted line represents Dr Beeley's "away from" temperature line and the red/orange straight line represent what Professor Gray has taken as the "next to" temperature, with the similar line immediately to the left (dotted black) representing a portion of the plot of the average container wall temperature on the "CSAV Shanghai". As Mr Phillips (who did not accept the validity of the "away from"/ "next to" temperature comparison, but was commenting on it), put it:

> *"So we see that even though the next-to temperature is higher, at its highest point, than the away-from temperature regime, a significant difference between those two regimes is that the away-from temperature regime is up at a higher level for much longer"* .

280. Accordingly, as CSAV contends, there would have been little or no appreciable difference between the temperature that the container would be likely to have experienced in consequence of the heating of No 3 FFOTS compared with the position without such heating (but with the heating of other tanks remaining the same) and any such difference would have been barely perceptible to the container. Further, there would have been some appreciable difference, there would have been little difference between the temperature to which the container would have been exposed due to heating of the tank and the temperature which it would have experienced if stowed somewhere elsewhere in the hold (at or above level 6) "away from" heat in accordance with the IMDG Code.

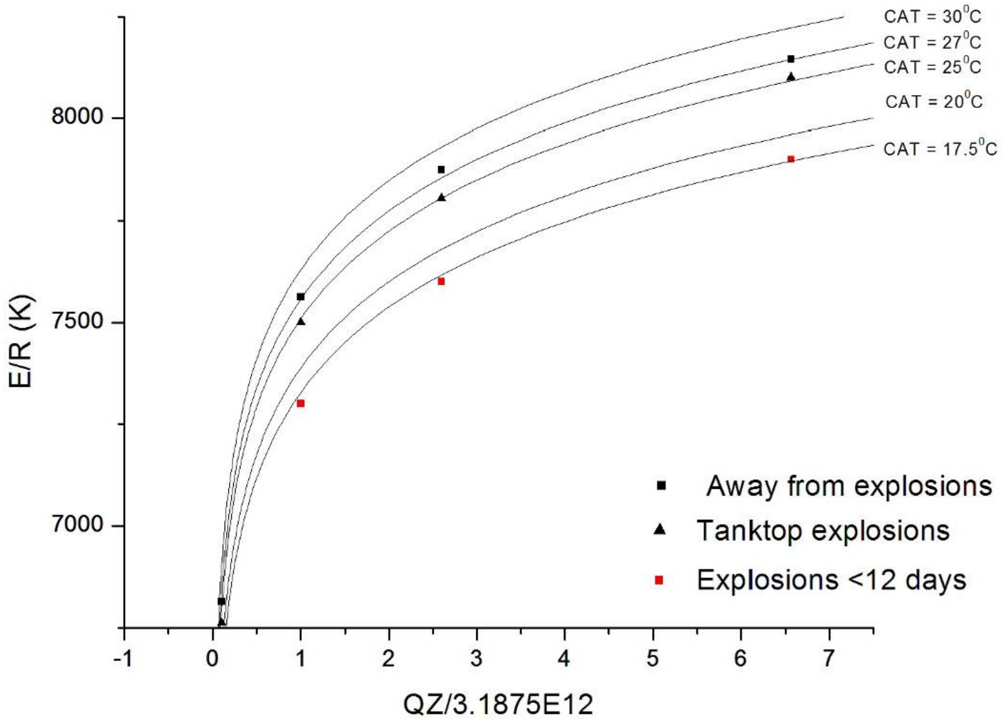
281. In my judgment the assessment and analysis set out in paras 274-280 is sound.

Professor Gray's back calculations.

282. Professor Gray performed the following exercise. Firstly he took the "away from" history shown in Dr Beeley's Appendix 11 to represent the temperature to which the container would have been subject if it had been stowed away

from the 15-09-06 location. He also took the temperature history of the container walls on the "CSAV Shanghai" voyage as measured by Dr Beeley i.e. with different temperatures on the different container faces (asymmetric heating) as if the "CSAV Shanghai" heating regime was that of the "Aconcagua". An average container temperature was calculated by taking the temperatures experienced on the different sides weighted by surface area. The maximum values taken were forward face: 44ºC; outboard 40ºC; bottom 39ºC; top 34ºC; inboard 34ºC; aft 25ºC. The maximum average container temperature was 36.4ºC which occurred about 5.2 days after heating started. These container wall temperatures are, of course, the result of the oil temperature in the tank being kept at the levels (63ºC or more) set on the voyage of the CSAV Shanghai, when in my judgment the container on the "Aconcagua" would probably only have been exposed to a container face temperature resulting from an oil temperature of more than 63ºC on the 29th December. He already knew the time that the cargo took to explode. He assumed that the cargo exploded on account of the heat received by it in consequence of the temperatures taken.

283. Armed with that information Professor Gray was able to work backwards through a series of calculations, using the equations described in Appendix 9 of his first report (the interaction theory) and the basic F-K theory with finite biot numbers. What he did was to assume figures for the two parameters QZ (the pre-exponential factor) and E/R (the activation energy divided by the universal gas constant) for the hypothetical material, and by integrating the relevant equations determined whether, on the assumed figures, thermal runaway did or did not occur. By repetition of this process he obtained enough pairs of E/R and QZ to be able to plot a graph of one against the other such that everywhere on the curve the time to ignition would be the time to ignition applicable to the "Aconcagua". The curve produced was as follows:



284. From that exercise he determined a number of things:

(a) if the material exploded on the tank top at the "Aconcagua" explosion time it would have had a CAT (representing hold air temperature) of approximately 25ºC. If the same material exploded in the away from position it would have a CAT of about 27ºC. In other words in order to explode on the tank top the material would have to be less stable (25ºC CAT) than material (27ºC CAT) which would have exploded away from the tank top;

(b) there cannot exist a material which would explode on the tank top but not in the "away from" position. All the data points for tank top explosion lie below the data points for "away from" explosion.

(c) He plotted a number of data points, labelled "Explosions <12 days", on the graph which represented the CAT that the material would have to have had in order to explode between days 5-15 on the voyage. Such material would have to have had a CAT of about 17.5ºC.

285. These results reflect the fact, to which Mr Phillips alluded, that, on the assumptions made, although the "next-to" temperature is higher at its highest point than the "away-from" regime, the latter regime involves a higher average diurnal temperature for longer. If the assumptions upon which these calculations are based are well founded and the method of calculation is

acceptable, then the material actually shipped must have had a very low containerised CAT – somewhere in the 25-27ºC range or lower. Further, bunker heating would appear to have had no causative effect on the explosion. If considerably greater bunker heating did not produce an explosion "close to" which would not have occurred "away from", it is highly unlikely that a lesser degree of bunker heating than in fact took place on the "Aconcagua" would have had that consequence.

286. Sinochem submits that the CSAV Shanghai results are at best an approximation of temperatures which might have been experienced on the "Aconcagua", but subject to qualifications which render the exercise so problematic as to be without value. Firstly, the exercise assumes that the oil temperature prior to heating was 15ºC. This takes no account of the bunkering in Busan. When the "CSAV Shanghai" bunkered in Hong Kong on 8th December with oil at 42ºC the container walls facing the tank reached 25ºC and remained over or around 20ºC for five days after that. Further the sea temperatures on the "Aconcagua" were around 20-25ºC for about 9 days after that. Secondly**,** after the peak average container temperature of 36.4ºC was reached, the container would still, as appears from Dr Beeley's Figure A7, experience heating from the oil in the tank, which would not have been picked up when the oil level had fallen beneath the level of the probes. The lower part of the tank would, however, have continued to heat the container and its contents as the level fell at the next transfer, and would have continued to heat the base until the next transfer after that. So the temperature cannot be assumed to have peaked as early as CSAV assumes. Thirdly**,** the air and sea temperatures were higher for the "Aconcagua" than the "CSAV Shanghai", which would have had some unquantifiable increase in the rate at which the tanks heated up.

287. As to the first point, it seems to me that the effect of bunkering in Busan on 27th November would be of limited significance by the second half of December. Such effect as it had would be to produce a source of heat not constituting any breach of contract by CSAV. As to the second, I accept that the peak average temperature may have occurred later and been somewhat higher than CSAV assumes, affecting the lowest two levels of quadritainers. As to the third, the air and sea temperatures in respect of the "Aconcagua" were higher. But I agree with Dr Beeley's view (i) that this is unlikely to have affected the temperature of the *tank* surfaces to any significant degree because heat transfer from the oil to the tank surface would be more efficient than transfer from the tank surface to the air (or vice versa); and (ii) that although the container surfaces could be affected to some degree it would not be equivalent to the difference in the environmental temperature between the two voyages and is likely to have been of limited significance for the reasons which he gives.

288. These are as follows. Heating of the container surface by the tanks does not only depend upon convection. Radiative heat transfer plays a significant part in the transfer of heat from tank surface to container. Air is largely transparent to radiation so that the temperature of the air flowing through the gaps between tanks and container will not materially alter the transfer rate. The

higher the temperature of the air being inspired into plumes in way of the tanks the higher the temperature of the heated surfaces of the container. However, the location of 15-09-06 is such that the air flowing over the container is likely to have been preheated as a result of having flowed over the surfaces of the lower "steps" of the tank side. Hotter air will heat up at a slower rate than colder air when passing over the tank steps. Pre-heating will therefore tend to minimise the effect of hotter ambient temperature.

289. Next Sinochem submits that the temperature histories assumed by CSAV both in the "*away from*" position – Dr Beeley's Appendix 11 -and in the "*next to*" position are predicated on so many assumptions as to render them useless for the purpose of reaching any justifiable findings. I do not regard them in that light. The "*away from*" history predicated by Appendix 11 cannot be treated as a precise assessment of the temperature profile in the upper parts of No 3 hold. But it is in my judgment a reasonable estimation of the sort of level likely to have been experienced. The "*next to*" figures are likely to overestimate the applicable regime on the "Aconcagua".

290. Lastly Professor Gray's calculations assume an even distribution of temperature within the container (hence his averaging) and a uniformity of the CH material. I consider in paras 299ff below the validity of that assumption.

Mr Phillips' models

291. Mr Phillips has carried out two different modelling exercises. The first was to postulate a semi-infinite solid[32] with one face, which was subjected to an immediate step change in temperature. He used a combination of heat transfer coefficients to represent the transfer of heat from the tank wall across the space between the tank wall and the container and then across the container wall itself, and two different figures for the thermal conductivity of CH, one being derived from Uehara and the other from Professor Gray's 2000 paper on UN 2880. He also used the Gurney Lurie tables, which enable one to determine, for a semi-infinite solid at a particular temperature, what, given the application of a particular temperature at the boundary of the solid, will be the temperature after a given time at a particular depth of penetration into the stow.

292. These calculations showed that, depending on the thermal conductivity figure chosen, the material about 0.1 or 0.3 metre from the edge of the container would have reached 49ºC after four days, although the temperature either 0.3 or 0.8 metres into the stow would have been around 22ºC.

293. Mr Phillips' approach assumes (a) a step change in respect of the oil from 15^o C to 63.3^oC which is then maintained for four days; (b) an instantaneous temperature rise on the surface of the solid to which the solid responds immediately at time zero; (c) that heat transfer within the solid takes place by

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[32] i.e. a solid without limitation of dimensions but to which a heat source is applied at a notional periphery.

conduction alone and in one direction only with no possibility of heat loss save into the solid itself; (d) that the calcium hypochlorite within the container is to be treated as one infinite body of material with a single face; (e) the use of 63.3° C as an oil temperature.

294. I did not gain a great deal from this exercise. The assumptions bear no relationship to reality (as to assumptions (c) and (d) see para 313 below) and the process did no more than show (i) that, upon those assumptions, heat will penetrate to the extent stated; and (ii) that the transfer of heat by conduction alone is a slow process such that within four days only the portions near to the side will have been heated.

295. Mr Phillips' second modelling exercise was made in response to Professor Gray's back-calculation which had been based on his 3D interaction model. Mr Phillips used the same numerical integration software as Professor Gray had used – *FlexPDE*. He had also used a number of parameters (set out in Table 1 of his fourth report) derived from Professor Gray or Dr Rose's calculations.

296. He sought to determine what would have happened to a quadritainer stowed next to a heated container wall so that it was heated on that face but no heat entered or left from the sides, top or bottom, but heat passed through the body in one direction. He assumed that the unheated side of the quadritainer was next to a similar quadritainer and that the second quadritainer was next to a third. The assumption that no heat passed through the sides of the quadritainers was tantamount to assuming that the quadritainer was part of a "wall" and was far enough away from the edges, top and bottom not to receive or reject heat through the sides or to the top or bottom. He regarded this as a reasonable and conservative assumption because, as he thought, the quadritainer on the bottom would not lose heat downwards to the heated tank top nor to the quadritainer above nor to the side.

297. On these assumptions he carried out a number of calculations by reference to five different assumed heating regimes, from which he established the CATs for material which would ignite next to the tank at the same time as the explosion occurred on the "Aconcagua", except for the first regime in which he established the CAT for a material that would ignite the first quadritainer as a result of heating from the bunker oil. The results were as follows:

Heating regime	**CAT**
	ºC
1. Bunkering at a bunker oil temperature of 42ºC Oil temperature rises from 15º to 42ºC in 0.5 days and falls back to 15ºC over 5 days	**23-24.5**
2. Oil temperature ramped up from 15ºC to a maximum of 63.3ºC in 4.5 days and then down to 30ºC in 3.5 days (A scenario regarded by Mr Phillips as too mild)	**32.5 – 33.5**
3. Oil temperature rises to 63.3ºC in a day, remains constant for a further 3.3 days and then falls to 30ºC in half a day	**34.5 – 36.5**
4. Oil temperature rises in a day to 63.3ºC, remains constant for a further 8 days, corresponding to 22-30.12.98 and then falls to 30º in half a day*	**42 - 44**
5. Bunkering for 24 hours followed by heating for 9 days	**45 - 46**

* Mr Phillips calculated that under the same regime the Donghai material would ignite if the oil was at 87.5ºC and the Zhenjiang material would ignite if the oil was at 77.5ºC.

298. Mr Phillips described this approach as conservative since (a) it took no account of the fact that some quadritainers might be heated from below; (b) the bulk oil temperature might exceed the measured transfer temperature particularly around the corners and edges of the tank which would have been more likely to have been affected by the rising plume of hot oil in the tank; (c) the CH would to some extent have been pre-heated by the bunkering process which would increase the tendency of the heated oil to ignite the CH.

Which model is the most appropriate?

299. There is a dispute as to which model is the most appropriate in order to assess the effect of a container which is heated asymmetrically.

300. Professor Gray considers that inside the container the quadritainers would be heated and cooled by convection. As a result the temperature within the container would be distributed among the quadritainers in a fairly even manner. The fact that some faces of the container would be hotter than others would make no practical difference to the distribution of heat. Consistently with this approach, Professor Gray's interaction theory assumes an even distribution and effectively averages the temperatures of the contents of the container, all the quadritainers being assumed to have temperature profiles which are temporally and spatially identical.

301. Mr Phillips considers that those quadritainers which were nearest to the heated faces would have been heated first and preferentially, and that averaging will under-estimate the susceptibility of the material to explode when it is heated asymmetrically[33]. Consistently with this view Mr Phillips' modelling assumed that the heat diffusion could be assessed on the basis that the quadritainers represent a single wall of uniform material exposed to a hot face (in effect a semi-infinite solid) and that the heat diffuses through it in one direction without being diffused to either side.

Discussion

302. Neither model is accurate. In order to decide which is the more appropriate model of the transfer of heat to and from the CH within the quadritainers it is necessary to consider (a) the physical form of the quadritainers; (b) the distribution of the CH within them; (c) how the quadritainers were stowed within the container; and (d) the likelihood of convection within the stow.

303. The physical properties of the quadritainers are apparent from photographs and actual samples:

(i) The quadritainers are designed to stack one on top of the other with the lid of one fitting into an annular recess in the bottom of another;

(ii) Each quadritainer is a roughly shaped body made up of two half mouldings welded together along a vertical join with noticeable variations in dimensions and with the apparently 'flat' surfaces not flat in any direction and with dimensions and planar regularity affected by surface irregularities and moulding projections;

(iii) There is a 'ridge' at top and bottom of the recessed portion in the centre of the face which is recessed by about 5-6 mm. When stacked side by side empty the gap is doubled;

(iv) When filled, the HDPE plastic material is deformed and the sides of quadritainers bulge outwards considerably (the width increasing by 12 to 14 mm).

(v) As Professor Gray concluded *"due to the bulging effect and the surface irregularities which will be different for each quadritainer, the fraction of the area of each surface which could be in direct physical contact with adjacent quadritainers will be rather small";*

(vi) Dr Beeley investigated the possibility of any appreciable contact between quadritainers and the container walls by practical experiments which involved an applied force of 15, 30 and 45 kg, used on

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[33] Mr Phillips gave the example of a container of chocolate with a melting point of 40ºC – an analysis based on an average wall temperature of 36.4ºC would not have identified that chocolate against faces heated at 40º would have melted.

quadritainers that had been painted so that the point of contact would appear on the wall against which they were pressed. These demonstrated that *“ the effect of bulging when filled [was] to cause any physical contact to be limited to the extremity of the convex shape so created and/or the protruding shoulders”.*

304. The result of these features is that, when the quadritainers are stowed side by side in a single layer, they will not butt up to each other to any significant extent. The bulges will keep most of the ‘flat’ faces well apart from each other so that the kegs will be in tangential physical contact only in way of the extremity of the bulge. Other than at that point of contact there will be a gap which permits the passage of air through it. That gap will increase still further when the next layer is put on top as the bulging then increases by a further 2mm as found by Professor Gray in his measurements. Since the stevedores are unlikely, when placing the quadritainers in the container, to have been able to achieve a compressive force similar to that employed by Dr Beeley in his ‘contact’ test, the gaps will probably have been larger than Dr Beely’s experiment showed.

305. The effect of the substantial rounding of the kegs at top and bottom on all four faces and on the corners of the quadritainers means that when the quadritainers are stowed together in columns and rows there is an appreciable void space at the tops and bottoms of each quadritainer. That void space surrounds the top and bottom of each quadritainer and extends some way down the quadritainer from the top. When the quadritainers are combined together *en masse* these voids form channels or shafts which run throughout the stow from the top to the bottom, from side to side, and from end to end.

306. The air channels more or less correspond to the free air space in the quadritainer in the ullage space between the top of the calcium hypochlorite and the top of the keg. By Professor Gray’s measurements this gives a height, after settling, of the body of calcium hypochlorite of 40 cm compared with a keg height of 58.2 cm. The ullage space would have allowed convection within the quadritainer.

307. The convexity of the quadritainers (exaggerated by their bulging when filled) and the nature of the corrugation of the container wall mean that the area of contact between container wall and quadritainer will be limited. In all cases, save for the kegs in the corners, such contact as there is will be on a single face. Where contact occurs the conductivity of heat will be reduced by air gaps and thermal resistance produced by the roughness and irregularity of the surfaces and protrusions of the plastic faces. As Professor Gray put it :

> *“As for the assumption that the quadritainers would touch the inner parts of the corrugations in the container this is not plausible. Only a small fraction, if any would be in contact as a result of (a) the convexity of the quadritainer walls, (b) the irregularities and weld lines on them, and (c) the different periodicities of the wall corrugations and the spaces between the quadritainers”*

308. Each container corrugation has three sections: (i) the section parallel and nearest to the quadritainer; (ii) the section parallel to and furthest from the quadritainer; and (iii) the linking section. Mr Phillips treated these three sections as equal in extent and his calculations assumed that one third of a solid face of a slab of quadritainers would have been in good thermal contact with the container wall. This is a considerable overstatement of the position.

309. In the light of these considerations I accept Professor Gray's evidence that the extent of direct conductive heat transfer into the quadritainers arising from the abutment of the quadritainers against the container wall would be minimal. As he put it:

> *" Given that one is now talking about quadritainers, and given the fact that when quadritainers are filled with 40 kilograms or 45 kilograms or whatever of calcium hypochlorite UN1748, the sides bulge out very significantly, they are quite convex, so the possibility of any large area of contact is extremely small. And even that area of contact, which can be looked at in detail, when you look at a quadritainer surface in detail, it's highly irregular, it's rather like the skin on one's fingers, it has walls and all kinds of valleys and hills and so on. So the possibility of a large value for the surface area in close contact is very small, and even when that particular area is in contact, the so-called thermal contact resistance of it would be very considerable, so the heat transferring through there would be very small as a fraction of the total being transferred by convective motion of the air. That's my opinion."*

310. So far as convection is concerned, I accept Dr Beeley's evidence that the effect of heating of the container wall would be to set up a convective flow of air adjacent to the heated wall which would cause the air in the container to circulate in the voids both around the periphery and within the stow. The thickness of the thermal boundary layer at the wall would be a centimetre or two at most. As a result any part of a keg more than that distance away from the wall would not be heated by the convective flow next to the wall so that the contents of the container would heat up relatively slowly. The convection currents would tend to cool the wall and even out the temperature rise throughout the cargo in the container. Further the closer the ambient temperature is to the heated temperature the less significant is the fact that heating was asymmetric.

311. Convection requires the presence of air which will support convective flow. Air will have been present (a) within the container at the aft (door) end, (b) within the channels of the corrugations running from top to bottom (with more air being available where the channels running from top to bottom between the curved edges of the containers coincide with a channel formed by the corrugation), (c) within the half channels running fore and aft and from side to side at the bottom of the stow, and (d) at the top of the stow. The effect of these various channels will be to distribute air in a relatively even fashion around the stow. The internal volume of the container has been calculated by Professor Gray as being c 33.32m^3. The volume of air left in the container when the CH in the quadritainers is taken into account is 15.21m^3. So the air

within and around the stow is about 45% of the total volume. The effect of asymmetric heating will be to provide a driving force for convection from the hotter side.

Conclusion on modelling

312. In my judgment, Professor Gray's interaction model, although not (and not claimed to be) an exact representation of the pattern of heat transfusion within the container, is the best available, and is to be preferred to Mr Phillips' semi infinite solid.

313. Mr Phillips' models (as well as the homely example of a container filled with chocolate) part company with the reality of:

(a) the shape of the quadritainers and the walls of the container;

(b) the lack of significant abutment between container walls and quadritainer sides;

(c) the channels available for the circulation of air permitted by those shapes;

(d) the available air within the container; and

(e) the likely effect of convection in dissipating heat.

Mr Phillips' models assume perfect insulation of each quadritainer such that there is no possibility of heat loss from the top, bottom or sides of the contents and a one-directional diffusion of heat into the stow. They also assume a solid stow of CH and an absence of air or air flow. In my view this is not realistic and markedly more unrealistic than Professor Gray's assumption of a broadly even distribution of heat.

314. Mr Phillip' second model is ostensibly an infinite slab, i.e. a slab with a defined thickness of three quadritainers but with its dimensions otherwise infinite. But, as he accepted, it can be treated as of infinite depth because the third quadritainer is sufficiently distant not to influence the calculations. As he put it, "*nothing happens there*". Heat does not diffuse into the fourth quadritainer before ignition takes place at a point less far into the stow. The second model is, therefore, for practical purposes another version of a semi-infinite solid, as modelled in the first exercise, although it does not have the instantaneous step-change of the first model but various different temperature profiles. It allows for heat transmission only in a single coordinate direction; and makes no allowance for convection. It thus suffers from similar defects to those of the first model.

315. Two factors contribute to the explosion of material: (a) the body size and (b) the chemical instability of the body. Mr Phillips' modelling assumes a body of infinite size. Using too large a body for a back-calculation based on a fixed explosion time results in the size contribution being over-represented and the

chemical contribution being under-represented. Mr Phillips accepted that the result of his modelling was to give activation energies which would be too high and therefore representing more stable material than would be the case if a finite model with set bounds for height, length and depth (i.e.3D) were taken. Further if the Phillips infinite slab model is run symmetrically it produces hopelessly low CATS which cast doubt on its utility as a model.

316. The model may also be said to assume what it seeks to prove. By eliminating the possibility of heat loss except in one direction it concentrates heating in the surface of the material and the first quadritainer so as to guarantee a point of ignition in the quadritainer nearest the heated face. If the assumptions of the model are correct, the result is informative, but the results cannot themselves justify the assumption.

317. These considerations lead me to prefer Professor Gray's model and his evidence as to its appropriateness as a guide to the likely level of magnitude of the CAT of a material which would have exploded on the tank top and away from the tank top on the "Aconcagua". I have also taken into account in reaching this conclusion his undoubted and longstanding experience in this particular field.

Mish mash: Mr Phillips' change of model

318. Paragraph 67 and Appendix 6 of Mr Phillips' fourth report give the impression that he had used one model and one set of scripts defining the model to perform his version of the exercise which Professor Gray had performed and to derive activation energies (E/R) and CATs.

319. In fact, as emerged in cross examination, Mr Phillips had used his asymmetric two-dimensional model to derive activation energies but had then used a further model when deriving CATs. That latter model was a 2D version of Professor Gray's 3D integration model (which assumed that the container and its contents were subject to convection and well stirred air both in the case of symmetric and, a fortiori, asymmetric heating). He had thus rejected the premise upon which Professor Gray's model was based, but had used figures based on that premise to derive CATs. Mr Rainey criticised what he described as the illogical "chopping and changing" of models resulting in a "meaningless mish-mash of results". In my view, Mr Phillips' approach was illogical and involved him using measurements in 2D which only had meaning in 3D, e.g. the outer surface area of the container of $76.1m^2$ which in his modelling became a perimeter of 76 metres length. If he had used Professor Gray's 3D interaction model he would have got CATs about 8 degrees higher[34] (although that would involve the illogicality of using a 2D model to calculate the E/R and a 3D model to derive the CATs). In those circumstances I find it difficult to place confidence in the CATs produced by Mr Phillips' second modelling exercise (or in the variation of them produced by using Professor Gray's calculations, which were based upon a different premise).

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[34] Mr Phillips' CATs are higher than Prof Gray's because he contends that quadritainers in one part of the container would get very hot before others and, therefore ignite sooner.

320. It follows that I do not accept that the asymmetrical heating to which the container was subject is likely to have had a pronounced effect on the quadritainers closest to the container wall. On the contrary the diffusion of heat in the container is likely to have well distributed.

Conclusions on the issues set out at paragraphs 59 (a) and (b)

321. I now, at last, bring together the several conclusions that I have reached in order to determine the issues identified at paragraph 59 (a) and (b) above.

322. The normal characteristics of UN 1748 of which a prudent carrier should have had knowledge were that the material was safe for carriage in containers on or under deck; but that it had a tendency to decompose if the temperature was as low as 60ºC, in which case it might explode; and that it should be kept away from sources of heat. The cause of the explosions that had taken place with UN 1748 material up to 1973 was probably rogue Japanese material of abnormally low thermal stability. CSAV did not know, nor should it have known, that UN 1748 could explode at CATs of 40ºC or below.

323. The heating which was applied to the tanks, and in particular No 3 FFOTS, was as described in paras 250 ff above. The effect of that on the ambient temperature in No 3 hold was likely to have produced temperatures in the upper parts of Hold No 3 (level 6 and above) in the high 30s. Normal UN 1748 should not have exploded if subjected to such temperatures. That, itself, implies that the material actually shipped was rogue material i.e. had characteristics which were markedly different from those of CH correctly described as UN 1748.

324. The results obtained from Professor Gray's testing of the Jingang samples suggest that CH from that source would, on occasion, be rogue. The calculations carried out by Professor Gray, on the assumption of a bunker heating regime which was hotter than that which prevailed on the "Aconcagua" establish to my satisfaction that the material shipped is likely to have fallen within that category and to have had an abnormally low CAT - somewhere in or around the mid to high 20s, or early 30s, far less than that which a prudent carrier would expect from UN 1748 and worse than the rogue UN 2880 investigated by Professor Gray. The nature of the evidence makes it impossible to be more definite. Even if the figure were out by a sizeable fraction the CAT would still have been abnormally low.

325. This conclusion is not invalidated by the absence of evidence of regular explosions of Jingang material. A factory with inadequate quality control or poor manufacturing standards and possible contamination may only produce material with a very low CAT on rare occasions. With the exception of the explosions on the "Contship France" and the "DG Harmony" (explosions of PPG material) such shipboard explosions as had occurred were from different manufacturers. The same product had not exploded twice.

326. In short, the evidence, taken as a whole, establishes that the CH shipped on the “Aconcagua” was a cargo of a dangerous nature of which CSAV neither had, nor ought to have had knowledge, and that CSAV had not knowingly consented to the shipment of CH of such a nature.

Causation

327. Under Article IV, Rule 6, Sinochem is liable to make compensation for the damages and expenses directly or indirectly arising out of or resulting from the shipment of the CH. As Judge Diamond, Q.C. made clear in *The “Fiona”*, this means that “*the indemnity is not limited to situations where the shipment of dangerous goods is the proximate or dominant cause of the carrier’s loss*” and is “*not limited to the situation where the shipment of a dangerous cargo is either the sole cause or the dominant cause of the carrier’s loss*”.

328. The explosion on board the “Aconcagua” resulted from the shipment by Sinochem of dangerous goods within the meaning of Article IV Rule 6. If the cargo shipped had not had an abnormally low CAT but a CAT of 60ºC or even 50ºC or less, the explosion would not have occurred.

329. Article III, Rule 1 provides:

> “*1. The carrier shall be bound before and at the beginning of the voyage to exercise due diligence to —*
>
> *(a) Make the ship seaworthy….”*

330. Article III, Rule 2 provides:

> *“2. Subject to the provisions of Article IV, the carrier shall properly and carefully load, handle, stow, carry, keep, care for, and discharge the goods carried.*

331. It is admitted that the stowage of the container in 15-09-06 was negligent, and, therefore, that CSAV was in breach of Article III, rule 2. Negligence and want of due diligence are the same thing.

332. Article IV provides:

> *“1. Neither the carrier nor the ship shall be liable for loss or damage arising or resulting from unseaworthiness unless caused by want of due diligence on the part of the carrier to make the ship seaworthy, and to secure that the ship is properly manned, equipped and supplied, and to make the holds, refrigerating and cool chambers and all other parts of the ship in which goods are carried fit and safe for their reception, carriage and preservation in accordance with the provisions of paragraph 1 of Article III. Whenever loss or damage has resulted from unseaworthiness the burden of proving the exercise of due diligence shall be on the carrier or other person claiming exemption under this article.*

> *2. Neither the carrier nor the ship shall be responsible for loss or damage arising or resulting from —*
>
> *(a) Act, neglect, or default of the master, mariner, pilot, or the servants of the carrier in the navigation or in the management of the ship."*

333. It is well established that a carrier, such as CSAV, is not entitled to an indemnity under Article IV, Rule 6 if its loss results from two causes (a) the shipment of dangerous goods not knowingly consented to; and (b) the carrier's overriding obligation of seaworthiness under Article III, Rule 1: *The Fiona [1994]* 2 Ll Rep 506; *The "Kapitan Sakharov"* [2000] 2 Ll Rep 255. It is not necessary to determine whether the carrier's breach was the dominant or merely an effective cause. It is sufficient that it was *a* cause. Sinochem contends that in stowing the container at position 15-09-06 where the container would be heated by the heated bunker tank CSAV was in breach of its duty under Article III, Rule 2.

334. That gives rise to the following issues:

(a) Who bears the burden of proof as to the causative effect (or the lack of it) of the negligent stowage?

(b) Was the stowage of the container at 15-09-06 either *the* or *a* cause of the casualty?

(c) Was that stowage a breach of the carrier's seaworthiness obligations under Article III, Rule 1 (a)?

(d) If not, did CSAV's fault amount to an "*act, neglect, or default in the management of the vessel*" within Article IV. Rule 2 (a)? If so, is CSAV still liable under Article IV, Rule 6?

(e) If CSAV's fault did not fall within Article IV, Rule 2 (a), is CSAV precluded from invoking Article IV Rule 6 because the indemnity under that Article is to be construed so as not to apply in the case of causative negligence?

Burden of proof

335. It seems to me that it is for Sinochem to establish that the stowage of the container at 15-09-06 had some causative effect. CSAV has established that the casualty resulted from the shipment of goods of the true danger of which it was unaware. Those goods had significantly abnormal characteristics. If the goods had had only the characteristics of which a prudent carrier should have been aware, the explosion would not have occurred. If Sinochem seeks to avoid a liability to which, unless bad stowage was a cause, it would be subject, it is for Sinochem to establish the causative effect of that stowage.

336. Mr Bright submitted that that was not so. Even if the goods were wrongly declared as UN 1748, they would not constitute dangerous goods within Article IV, Rule 6, if, notwithstanding the misdescription, they would have been carried without danger if the instruction to stow away from a source of heat had been followed. In such circumstances the goods would not have been different in kind or type to normal goods. Accordingly, to make good its case, CSAV had to show that the sole cause of the explosion was the character of the cargo and that it would have exploded even if carried in accordance with the carriage instructions that the Code gives. For the reasons set out in the preceding paragraph I do no accept that that is so. Further it is apparent that the cargo would have exploded (at any rate in some locations) even if stowed away from a source of heat.

337. As to the causative effect of the stowage there are a number of possibilities. The first is that the CH actually shipped would have exploded *wherever* it was stowed on the vessel. If so, the fact that it was stowed at 15-09-06 is without significance. Stowage there made no difference. A second possibility is that the CH actually shipped exploded at level 15-09-06 but would not have done so if it had been stowed *anywhere else* on the vessel. In that case the stowage there would have been a cause of the explosion, but not the only cause. A third possibility is that, if the CH shipped had been stowed away from 15-09-06 it would still have exploded *in some places but not in others*. In that event the first relevant question, as it seems to me, is where would CSAV have (properly) stowed the container? If in the place in which CSAV would properly have stowed it it would have been safe, then the casualty was caused by the bad stowage. If it would have been properly stowed in a place where it would still have exploded, then the bad stowage has made no difference.

338. CSAV submitted that it was unnecessary to examine these possibilities because, if the cargo had been properly described, CSAV would never have accepted it for shipment in the first place. I do not agree. I accept that if the cargo had been declared as it should have been it would not have been accepted for shipment. Such a declaration would have to have revealed that it was an abnormal cargo, likely to have an exceptionally low CAT and at risk of exploding in a normally heated hold. That does not, however, mean that the shipment of dangerous cargo must be regarded as the only operative cause of the explosion which entirely eclipses any causative effect of stowing the container in 15-09-06, a place that was to become next to a heat source, when the instructions in UN 1748 call for it to be stowed away from heat.

Conclusion on bunker heating causation

339. Sinochem has not, in my judgment, established that the heating of No 3 FFOTS on the voyage from Los Angeles was a cause of the explosion. The likelihood is that it was not. The temperature in Hold No 3 at level 6 and above, even without heating of the bunker tanks, is likely to have been in excess of 30ºC. The effect of heating the hold by the use of No3 FFOT (P & S) would probably have meant that the temperature reached the high 30s. If that heating had not included the heating of the No 3 FFOT (P & S) the temperature is likely to have been around the mid 30s on account of the effect

of the use of No 3 AFOT (P & S) and No 2 P & S on the voyage and the ambient temperature as the vessel left Los Angeles and entered the tropics. The difference between the temperatures which the container would have experienced if stowed at 15-09-06 without heat being applied to the No 3 FFOT (P & S) and the temperature which it did in fact experience does not seem to me likely to have been sufficient to make the difference between safety and explosion, or to have acted as the operative perturbation in respect of a material with a very low CAT, compared with the ambient temperature perturbation produced by the sharp increase in temperature after the vessel left Los Angeles and entered tropical waters together with the earlier heating derived from the sources identified in para 272 (a) and (b) above. The increase in temperature arising from an oil temperature rise to 63.3° on 29th December 1998, in circumstances where the oil levels were falling, seems to me unlikely to have had any causative effect.

340. Mr Bright warned me of the danger, classically exemplified in *The "POPI M"* [1985] 2 Ll. Rep 1 of thinking it necessary, when presented with two competing cases, of deciding in favour of one of them. I do not, however, accept that the evidence is in so unsatisfactory a state that the only just course is to leave the outcome of the case to the incidence of the burden of proof. Sinochem cannot say what exactly was shipped. It is, therefore, necessary to decide what inferences can be drawn from a consideration of the characteristics of other normal cargo and other Jingang material, the history of UN 1748 and UN 2880, and the temperatures prevailing on the voyage, amongst other things.

341. If that is wrong, it is necessary to consider what would have happened if the container had been stowed in some other place. If the container had not been stowed at 15-09-06 it would, if carried, have to have been stowed elsewhere. If it could properly, and would in fact, have been stowed elsewhere in No 3 hold, where the explosion would still have occurred, the fact that it was stowed at position 15-09-06 will have made no difference.

The meaning of "away from".

342. UN 1748 requires CH to be stowed "*Away from*" sources of heat. That must include shipboard sources of heat, of which a heated bunker tank is one. Paragraph 14.13 of the General Introduction defines sources of radiant heat as including heating coils. Section 14 of the Code, headed "*Stowage*", provides, in para 14.13:

> *"When it is recommended in individual schedules that the substances should be stowed shaded from radiant heat, stowage under deck should be "away from" sources of heat, including .....heating coils etc".*

343. Sinochem submits that the obligation to stow CH away from a source of heat is not satisfied by stowing it somewhere higher up in the hold to which heat would naturally percolate. To do so would, it is submitted, be to defeat the object of the injunction by exposing the cargo to the very risk that it was designed to avoid.

344. I do not accept this. CH is not a cargo which is required to be stowed on deck. The instruction is to stow away from "*sources of heat*", not from heat itself, nor from the ambient temperature ordinarily to be found in the top of a hold. UN 1748 makes no provision, as other parts of the Code do, for CH to be stowed in a cool part of the ship or protected from heat:(see Class I (Explosives) Code para 5.3.1.1, Class 2 (Gases), para 3.2.1; Class 3 (Flammable liquids) para 5.2.1; which also provides for stowage away from sources of heat; Class .1 (Flammable solids); Class .2 (spontaneously combustibles) and Class 4.3 (Dangerous when wet) paras 10.2.2 and 3.2.2; Class 6.1 (Toxic Substances) para 3.3.2; and Class 8 (Corrosives) para 4.2.2. Many of these provisions also provide for stowage away from sources of heat.

345. Regulation 6.1 of SOLA provides:

> "
>
> *Stowage requirements*
>
> *2. Dangerous goods shall be stowed safely and appropriately in accordance with the nature of the goods. Incompatible goods shall be segregated from one another."*

Segregation requirements

346. Paragraph 15 of the General Introduction of the Code, headed "*Segregation*" provides in para 15.1 as follows:

> *"15.1.2 The International Convention for the Safety of Life at Sea, 1974, as amended, requires in regulation 6.1. of part A of chapter VII that incompatible goods shall be segregated from one another*
>
> *15.1.3 For the implementation of this requirement, two substances or articles are considered mutually incompatible when their stowage together may result in undue hazards in case of leakage or spillage, or any other accident.*
>
> *15.1.4 The following segregation terms are used throughout this Code:*
>
> *1. "Away from"*
> .....
>
> *These terms are defined in 15.2 and their use in regard to the different modes of sea transport is explained in the other subsections of this section."*

Paragraph 15.1.17 then provides:

> "*For the purpose of the segregation requirements for the various modes of carriage by sea the section has been subdivided as follows:*
>
> *15.2 Segregation of packages*
>
> *15.3. Segregation of freight containers on board containerships"*

347. Paragraph 15.2 deals with the Segregation of packages. Paragraph 15.2.1.1. provides:

> *"The requirements of this subsection apply to the segregation of:*
>
> *1 Packages containing dangerous goods and stowed in the conventional way;*
>
> *2 …."*

Paragraph 15.2.2.1.1 then goes on to provide, in this context, a definition of "*away from*" which requires effective segregation of incompatible goods and allows carriage in the same hold provided a minimum horizontal separation of 3 metres, projected vertically, is obtained.

348. Paragraph 15.3 deals with "*Segregation of freight containers on board containerships*". A table at 15.3.2. then provides that when the segregation requirement is "*away from*" there is no restriction on stowing a closed container, whether on deck or under deck, next to another container in a horizontal line whether in a fore and aft or in an athwartships position. Further, stowage of one container on top of the other is permitted. By comparison if the segregation requirement is "*separated from*" two containers are not to be in the same vertical line unless segregated by a deck. In a horizontal line one container space separation was required.

349. The stowage instruction for UN 1748 is that it should be stowed "*away from*" sources of heat. The use of inverted commas cannot, however, be intended to import into the instruction to stow away from sources of heat the segregation requirements laid down for packages, and does not do so because the segregation requirements in respect of containers do not apply to segregation of a freight container and a shipboard source of heat. The segregation requirements, whether in respect of packages or containers, relate to two sets of goods which are incompatible with each other.

350. Whether or not a container has been placed "*away from*" a source of heat depends on whether the container in the place where it is in fact stowed can properly be described as away from the source of heat. I accept CSAV's submission that a container should be regarded as away from the source of heat constituted by the heated bunker tank if there is at least one container space between the container and the source of heat.

Where would CSAV, acting competently, have stowed the container?

351. If the stowage planner had realised that he could not stow the container in 15-09-06 he would have to have stowed it in some other position when it was loaded at Busan. There were numerous places where, in that event, he could have put it. Much of the cargo consisted of empty containers being carried back to base; so that there was considerable room for manoeuvre. The likelihood is that, if he was acting competently, it would have been stowed in the forward part of No 3 hold, where it was in fact stowed, but higher up i.e. at least level 8 and probably in levels 10 and 12. I say that for the following reasons. This would have left the entirety of the aft section for 40' containers, as was the actual stow: see F5/227 & 229.

352. Cargo loaded at Busan bound for San Antonio, the port of discharge of the container, was loaded into holds 3 and 4. Hold No 3 was the hold in which the planner in fact chose to stow the container. But, as Mr Bright pointed out, the container was put where it was because it could conveniently fit into a slot for one 20' container and it and the tank next to which it was stowed would then support the 40' containers loaded on top of it. Another 20' container was stowed in the corresponding position on the port side. There were then more containers with 40' container stowed on top of it.

353. There was, however, a good reason to use No 3 for the container. UN 1748 provides that:

> *"The possible need to open hatches in case of fire to provide maximum ventilation and to apply water in an emergency, and the consequent risk to the stability of the ship through flooding of the cargo space, should be considered before loading"*

354. That provision warns the planner to take into account the need to apply water in an emergency and that the risk of flooding from such water affecting stability should be considered. Hold No 3, like hold No 1 (which contained goods bound for ports other than South American ports) was fitted with sprinkler pipe work in the hatch covers (and was thus approved for the carriage of dangerous goods of all classes). Hold No 4 was not. Stowage high up under deck in hold no 3 would mean that the container was close to a source of water in an emergency and well away from a source of heat[35]. I note that the IMDG Class 4.1. cargo loaded at Los Angeles bound for San Antonio was stowed under deck in hold 3 at level 12.

355. There was loaded into the bottom of No 3 hold a general copper cargo spanning rows (working from port to starboard, left to right on the plan) 06, 04, 02, 01, 03 and 05. This general cargo was then over stowed with 40' containers which were supported by brackets attached to the cell guides. These

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[35] There is some evidence – in a report of 15th March 1999 from Burness, Corlett & partners, who attended the vessel in January 1999, that after the casualty the sprinkler system to hold No 3 was found not to be connected. Whether that was so before the casualty is unknown. There is no reason to suppose that it was not connectable or that the stowage planner would have been aware that it was unconnected (if it was at the relevant time); or incapable of instructing that it should be.

containers were somewhat higher than the standard container as a result of which their tops would not have been in line with but slightly above the tops of the adjacent 20' containers. It is possible to over stow two 20' containers with one 40' container but not vice versa (since there is nothing in the middle of the top of the 40' container with which the aft end of one and the forward end of another 20' container can engage).

356. Sinochem submits that, in those circumstances, if the container was to be stowed in the upper part of No 3 hold it would have been necessary to reposition every single 40' container and not to carry the general cargo which was probably carried at the base of the stow, and 20' containers would have to be stowed in their place. The prudent planner would not have been so senseless. He would have swapped the container with a single 20' container somewhere else on the vessel or stowed it on deck.

357. I do not accept this. Even assuming that the general cargo and 40' containers stowed in rows 05 to 06 remained[36], this still left rows 10, 08, 07, and 09 in Bays 13 and 15. Stowage in positions 13-10-12, 13-10-10, 13-8-12,13-8-10, 13-07-12, 13-07-10 13-09-12 and 13-09-10 was available (even if, in the case of rows 7 and 9 and 8 & 10 that would mean that empty 40' containers could not be carried (as they were) in all of those rows, and the container would have to have been under stowed by other 20' containers. There were 21 of them to be carried from Busan, and 9 from Los Angeles, to San Antonio. Similar positions were available in Bay 15.

358. As to what would have happened if the container had been stowed in the upper reaches of No 3 hold, the exercise carried out by Professor Gray is instructive. He assessed the likelihood of the existence of material which would explode on the tank top at 15-09-06 but which would not have exploded in the ambient hold temperatures likely to have prevailed in hold no 3 on the tropical voyage and given heating from bunker tanks bounding the hold. He concluded that material with a CAT of approximately 25ºC would explode at the tank top and that material with a CAT of approximately 27ºC would explode in the "away from" position, and that, in the light of the lie of the data points along the curves, there was no material which would explode at the tank top which would not have been set off by ambient temperatures elsewhere. That exercise was conducted by reference to the heating that took place on the "CSAV Shanghai" which was, as I have found, considerably more elevated than that which applied on the "Aconcagua". If a material could not be found which would have blown up on the tank top at the "CSAV Shanghai" temperatures but which would not blow up elsewhere, it is unlikely that a material exists which would have exploded on the tank top of the "Aconcagua" but would not have exploded elsewhere in hold No 3.

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[36] Some of the copper came off at Busan; and some – perhaps all the remainder – at Keelung. If and to the extent that that cargo came off it would have been possible to use the vacated rows for the storage of 20' containers.

Unseaworthiness

359. If I am wrong on that, it is necessary to consider whether in stowing the container in 15-09-06 CSAV was in breach of its obligation to exercise due diligence to make the vessel seaworthy. In my judgment it was not.

360. The carrier is "*bound before and at the beginning of the voyage to exercise due diligence to make the vessel seaworthy"*. In order for the carrier to be in breach the vessel must be unseaworthy at the commencement of the voyage. Bad stowage which endangers the safety of the ship and cannot readily be cured on the voyage is unseaworthiness: *Ingram & Royle Ltd v Services Maritimes du Treport* [1913] 1 KB 538. Thus in *The "Kapitan Sakharov"* [2000] 2 Ll. R. 255 the vessel was unseaworthy because there had been stowed in the aft part of her No 3 hold a highly inflammable liquid called isopentane in a confined and ill ventilated space. Unseaworthiness is usually "*a physical state*" (per Auld, LJ, ibid) existing at the commencement of the voyage which endangers the safety of the vessel. That state existed in that case because isopentane with a flash point well below 0º C and a boiling point of about 28º C was a source of immediate danger in a voyage in July in the Arabian Gulf. The proximity of the container to No 3 FFOTS does not, of itself, constitute a dangerous physical state. But there can be unseaworthiness, not classifiable as a physical state, e.g. where there are incompetent officers or crew, which is not here alleged.

361. A commonly applied test is whether a prudent shipowner if he had known of the defect would have sent the ship to sea in that condition: per McNair, J in *M.D.C. Ltd v N.V. Zeevart Maatschappil "Beuerstraat"* [1962] 1 Lloyd's Rep 180. Another is to ask whether the vessel was in all respects fit to carry her cargo safely to its destination having regard to the ordinary perils to which such a cargo would be exposed on the voyage: see *The "Kriti Rex"* [1996] 2 Ll Rep 171 That formulation is not, however, to be interpreted as a warranty that the vessel will successfully overcome all ordinary perils. In *Bradley & Sons Ltd v Federal Steam Navigation Co Ltd* [1926] 24 Ll Rep 446 Scrutton LJ adopted the formulation that the ship must have that degree of fitness which an ordinary careful owner would require his vessel to have at the commencement of her voyage having regard to all the probable consequences of it.

362. But a vessel is not unseaworthy because, at the commencement of the voyage, there is something which may need a correction which can readily be made and the need for which has not been hidden. In *Steel v The State Line Steamship Company* [1877] 3 A.C. 72 Lord Blackburn distinguished between (i) a port hole left open on the orlop deck with cargo piled up high against it, where no one could see whether the port hole had been left open or not, in circumstances where it would require a great deal to time to remove the cargo; and (ii) a porthole left open in a cabin which could be shut at a moment's notice as soon as the sea became rough. In the latter case the vessel would not be unfit to encounter the perils of the voyage because the matter could be set right within a few minutes and "*if they did not put it right after such a*

warning, that would be negligence on the part of the crew, and not unseaworthiness of the ship".

363. In *Hedley v Pinkney & Sons Steamship Company* [1894] A.C. 222 Lord Herschell, LC, speaking for the House, expressed his agreement with Lord Blackburne and held that there was no unseaworthiness in a case where moveable stanchions had been put on board, to bring the bulwarks opposite the hatchways up to the level of the other bulwarks when the hatchways were not in use, which had not been fitted. As a result a seaman fell into the sea and was drowned. The vessel had all the necessary equipment on leaving port and the fault lay in not making use of the equipment provided.

364. The "Aconcagua" was only potentially in danger if the No 3 FFOTS was heated on the voyage to San Antonio. If no such heating had taken place the container would, so far as anything concerning the vessel was concerned, be entirely safe. In those circumstances the vessel cannot be treated as unseaworthy at the commencement of the voyage unless such heating was bound to occur because No 3 FFOTS had to be used on the voyage to San Antonio; or if such heating was pre-programmed to occur, or if the crew were incompetent in the sense that they were so ill trained that they did not know they had to protect heat sensitive cargoes. This is not alleged.

365. In the present case the vessel did not have to use the No 3 FFO tanks on the voyage from Busan to San Antonio. She had not used them during the voyage from Busan to Los Angeles. At Los Angeles she had bunkered and all tanks were available for use on the next leg of the voyage to San Antonio. The vessel bunkered No. 2S, Nos. 3AFOT (P & S) and Nos. 4P and 4S and, in addition, had available No. 3 FFOT P.

366. Whether or not those tanks were used would depend on an operational decision made during the voyage. The operative fault lay not in the stowage of the container at 15-09-06 but in the decision to use and heat No. 3 FFOTS and the failure of the Chief Officer and the Chief Engineer, in deciding which bunkers to use on the leg out from Los Angeles, to appreciate that a cargo described as one to be stowed away from sources of heat, ought not to be heated by the bunker tank around it, and that bunkers from other tanks should be used. To heat No 3 FFOTS was negligence but not unseaworthiness. The obligation to take care to make the vessel seaworthy does not mean that the ship must be immune from the negligence of her crew.

367. A vessel may be unseaworthy if there is no system in operation to deal with the ordinary incidents of a voyage, including the need for the cargo to be stowed in a way that does not endanger the ship. That is not this case.

368. As the arbitrators record at paras 31-32 of their Award, before the vessel sailed the Chief Officer received a dangerous goods list with details of the cargo. After she sailed he checked the stowage plan using the vessel's loading computer. That computer had on it DAGO (Dangerous Goods) software. That would have thrown up, when UN 1748 was entered, a flashcard indicating that stowage was to be away from sources of heat. Whether he noticed this is

unclear. In his statement to the arbitrators he said that he interpreted this instruction as satisfied if the goods in question were in a container. That was an error.

369. Mr Gruener's evidence was that he would inform the Chief Officer when one tank was coming to an end what tank he planned to use next (the tanks in or to be in use being a matter of daily discussion). The vessel's operations manual stated that on the completion of loading at each port there should be a discussion between the Chief Officer, the Chief Engineer and the Master. The Chief Engineer confirmed that such meetings took place at which there would be a discussion about the bunker consumption for the next leg of the voyage i.e. the period over which a tank or set of tanks would be used.

370. In those circumstances (a) the Chief Officer had before him the information that the cargo was UN 1748 and, therefore, should be stored away from heat; and (b) there was a system for addressing the question as to which tanks should be bunkered at different stages on the voyage. The Chief Officer could and should have assessed the acceptability of heating the tank next to the container and objected to the heating of No 3 FFOTS. He did not do so. Nor did the Master or the Chief Engineer.

"*Act, neglect, or default in the management of the vessel*"

371. Subject to the provisions of Article IV, CSAV was bound under Article III Rule 2 "*properly and carefully to keep, care for and carry*" the cargo. Heating No 3 FFOTS when a container of CH was stowed on top of it was a failure properly to care for and carry that cargo.

372. The heating of the cargo was, however an "*act, neglect or default in the ... management of the ship*". The risk of loss arising therefrom was, therefore, an excepted peril and CSAV were under no liability in respect of it. The arbitrators so held; and, in my opinion, rightly so. They cited the following passage from Cooke on Voyage Charters , summarising the effect of *Gosse Millard v Canadian Government Merchant Marine* [1929] AC 223:

> *"The principal inquiry, therefore, is whether the act or default which caused loss or damage was done (or left undone) as part of the care of the cargo or as part of the running of the ship, not specifically related to the cargo. Some functions of machinery on board are clearly related only to cargo"*

and regarded improper bunker heating as analogues to errors in ballast management which was well established to fall within the Article IV, Rule 2(a) exception as "management of the ship" (see *The "Glenochil"* [1896] P 10 and *The "Rodney" [1900]* P 112). Heating of bunker oil for transfer to the engine room was, in their view, with which I agree, "*patently*" something done as part of the running of the ship.

373. In "*The Fiona*" Judge Diamond concluded, obiter, that the indemnity under Article IV, Rule 6 could not be relied on where the casualty was caused by a

combination of a dangerous cargo and a non-excepted peril such as a want of due diligence to make the ship seaworthy "*or negligence in the loading handling or carriage of the cargo*". The implication of his decision is that Article IV, Rule 6 could be relied upon if the second cause was an excepted peril. I reach the same conclusion. If the casualty was caused by the shipment of dangerous goods and by a cause for which CSAV was not liable, there is no reason why CAV should be disentitled to the Article IV, Rule 6 indemnity.

Causative negligence not within the exception

374. If, however, contrary to my view, the Article IV, rule 2 (a) exception is not applicable, and the casualty was caused by a combination of (a) the shipment of dangerous goods and (b) the heating of the No 3 FFOTS, then, as it seems to me, CSAV would not be able to recover an indemnity for the reasons given by Judge Diamond. On that hypothesis the casualty was in part caused by the operation of a non-excepted peril namely the negligent bunker heating for which CSAV was responsible. The exclusions and indemnities contained in Article IV are predicated on the carrier showing that the loss for which he is said to be liable, or in respect of which he claims an indemnity, was alone caused by a peril falling within Article IV (e.g. an act in the management of the vessel or the shipment of dangerous cargo). They are not to be construed as applying to loss caused in part by the negligence of the party which seeks to invoke the Article.

Summary

375. In summary I have decided the following:

(a) The CH shipped on board the "Aconcagua was of a dangerous nature of which CSAV did not, nor ought it to have had, knowledge;

(b) Sinochem, on whom lies the burden of proof, has not established that the heating of No 3 FFOTS was a cause of the explosion. The likelihood is that it was not;

(c) The heating of the No 3 FFOTS did not constitute or result from unseaworthiness;

(d) The heating constituted an act, neglect or default in the management of the vessel, which is an excepted peril;

(e) Accordingly, even if the heating had been causative, CSAV would still be entitled to an indemnity under Article IV, Rule 6.

Damages

376. The parties have agreed that the only matter that I should address at this stage is the recoverability of $ 27,750,000 the amount paid by CSAV in settlement of the claim made against them by the Owners in the arbitration. The Owners'

claim as at the date of the settlement on 25th April 2006 was for about $ 29,000,000 principal together with interest of c $ 17,700,000 and costs in the sum of £ 3,750,000.

377. Miss Gotts on behalf of Sinochem submitted that the only facts relevant for the purpose of deciding whether it was reasonable to settle and in the settlement amount were (a) the evidence available at the time and (b) the reasoning of the person who made the decision to settle. Since CSAV has elected to call no evidence as to the circumstances leading up to the settlement or as to its make-up or as to the reasonableness of making it on the terms which it did and at the time when it did, it has not proved its loss and the court can make no relevant findings.

378. I disagree. The position unsuccessfully taken by CSAV in the arbitration was, so far as causation is concerned, effectively the same as that taken, now unsuccessfully, by Sinochem in this action. The decision I have reached in this action shows that Sinochem would, had they not settled, in all probability have lost the arbitration. The Owners' expert witnesses were Professor Gray and Dr Beeley, and it is the case presented by their evidence that I have for the most part accepted. The likelihood is that the arbitrators would have accepted it too.

379. I am wholly satisfied that the settlement by CSAV was both a reasonable thing to do and a reasonable amount (being approximately 58% of what was claimed) , particularly having regard to the findings in the interim award and the dismissal by Morrison, J of CSAV's appeal under section 69 of the Arbitration Act 1996.

380. I should like to express my appreciation for the very high quality, content and clarity of the submissions made to me by both sides. I do not intend to detract from that by setting out in Appendix 3 some problems that arose in the mechanics of handling this case and some respects in which useful lessons can be learned.

APPENDIX 1

3d representation of No 3 hold

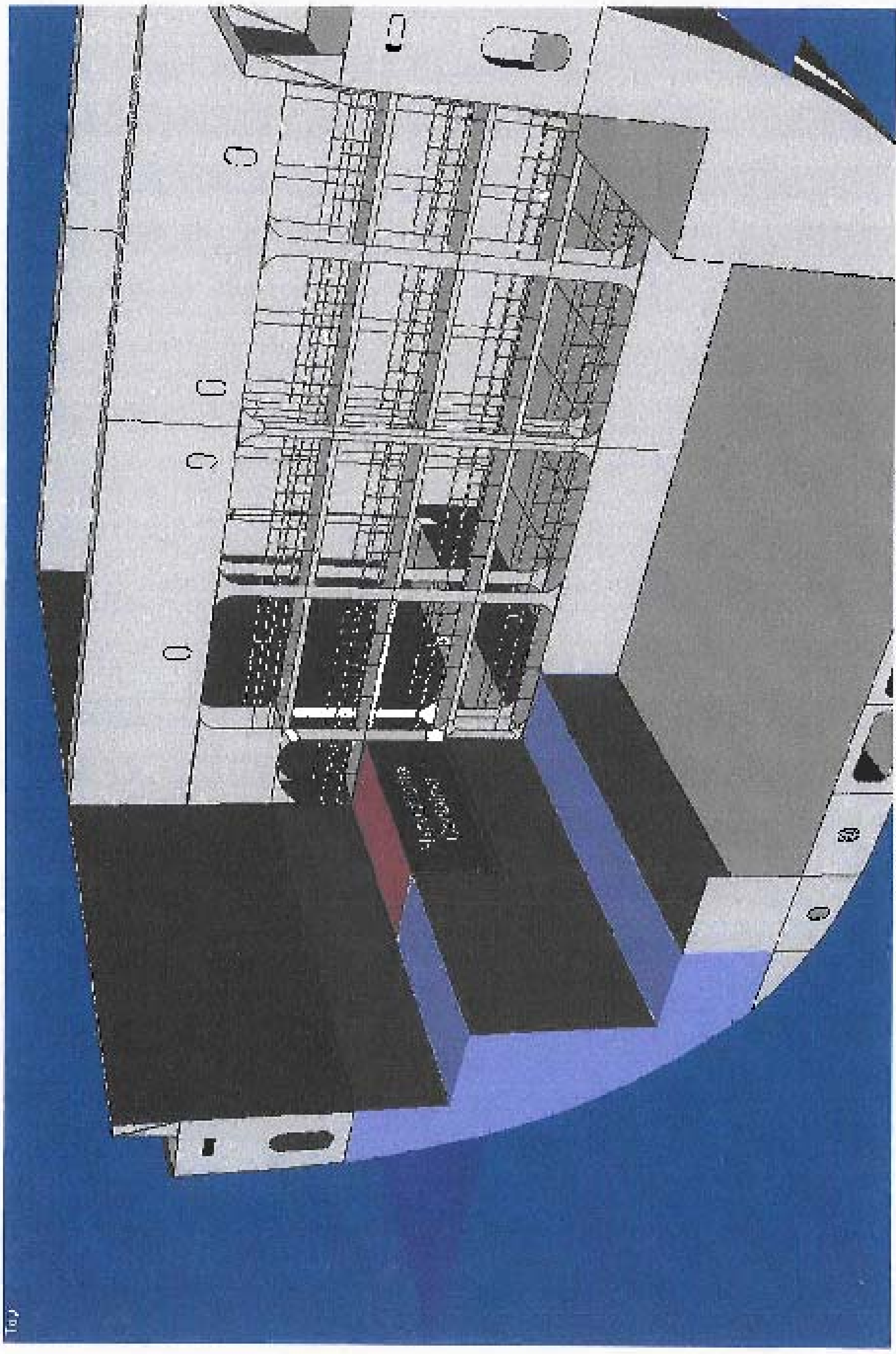


Figure 3 - No.3 Cargo Hold, Looking Aft

Diagram of No 3 hold

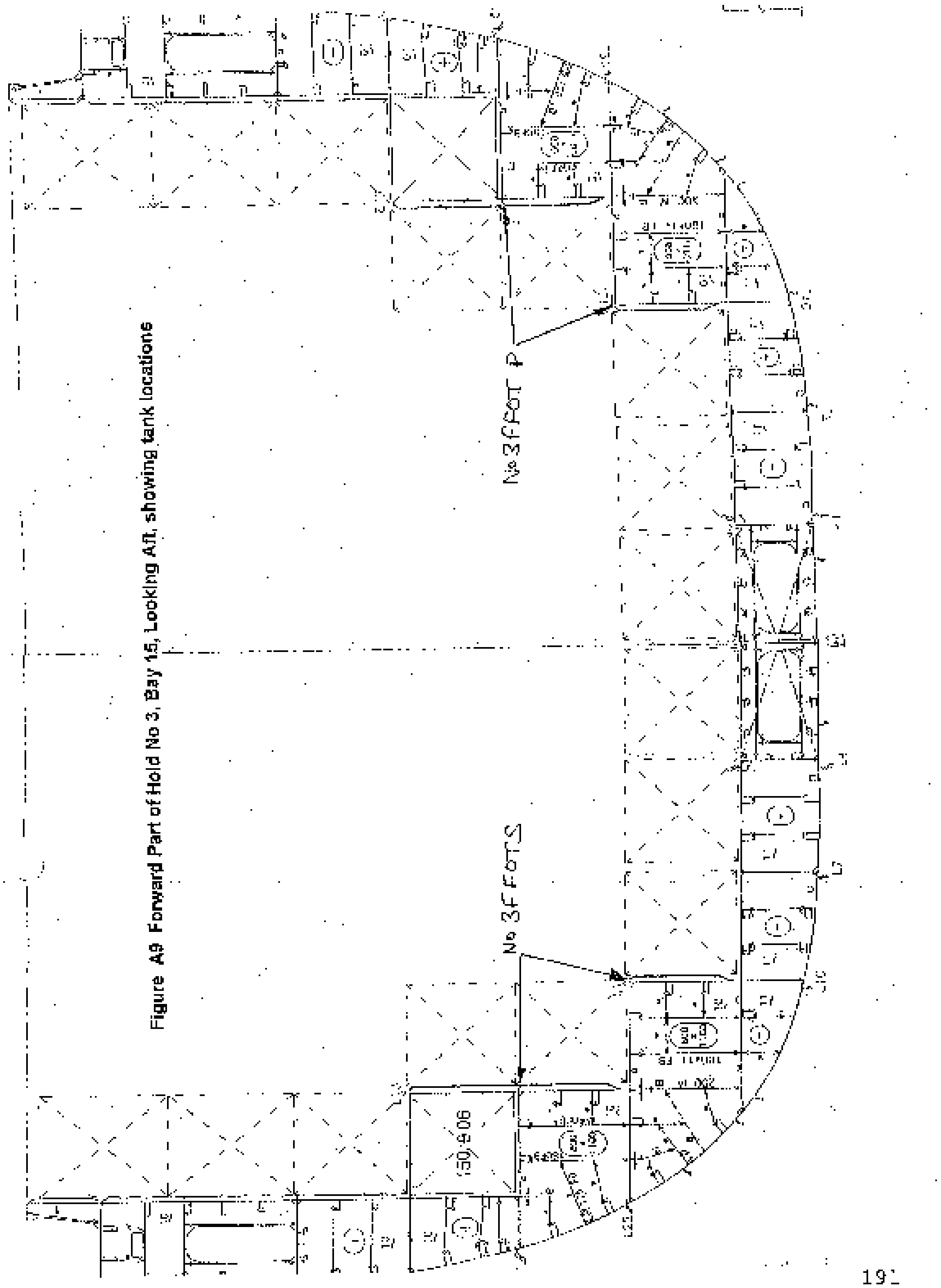
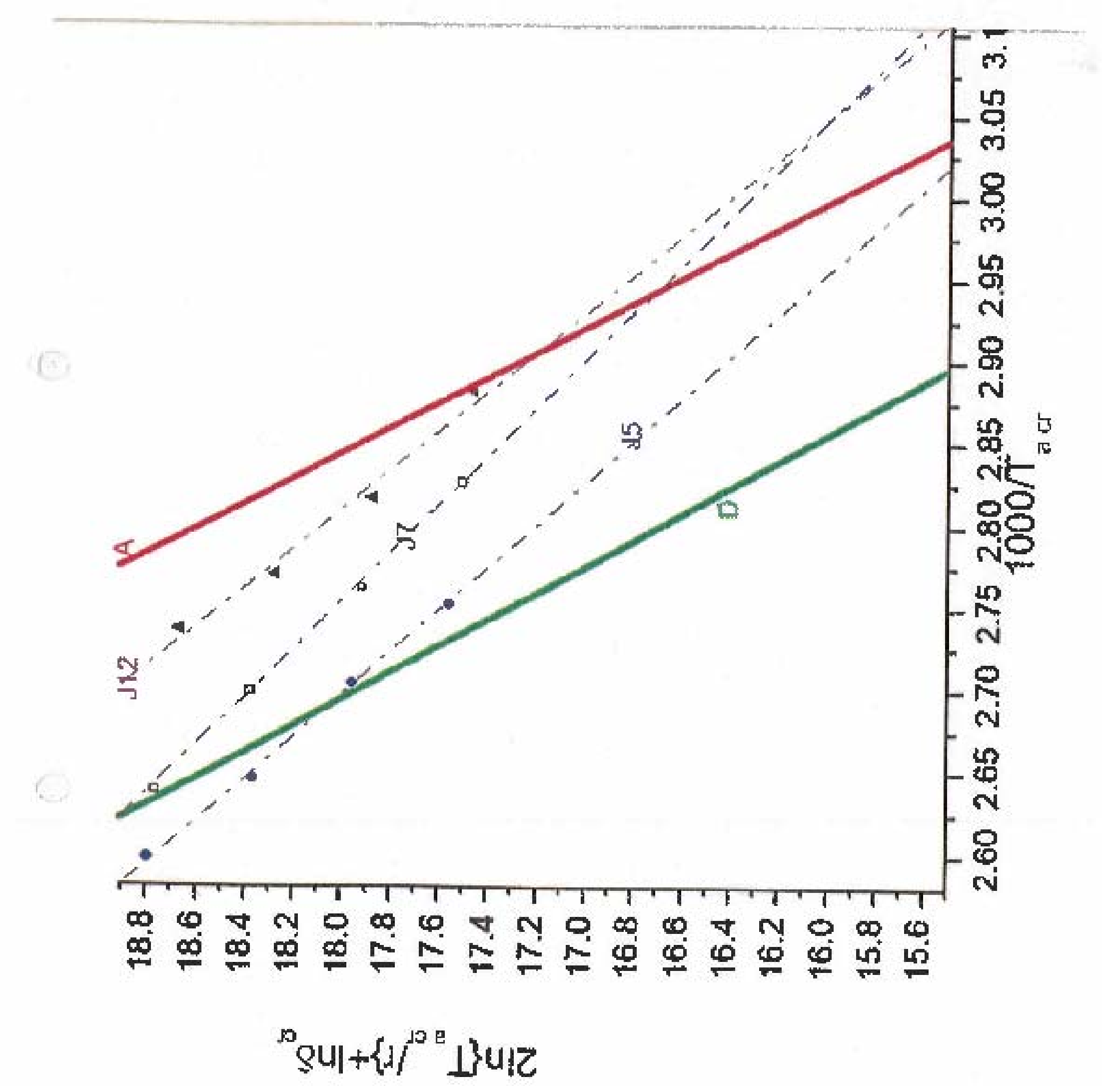


Figure A9 Forward Part of Hold No 3, Bay 15, Looking Aft, showing tank locations

Professor Gray's plot of various materials



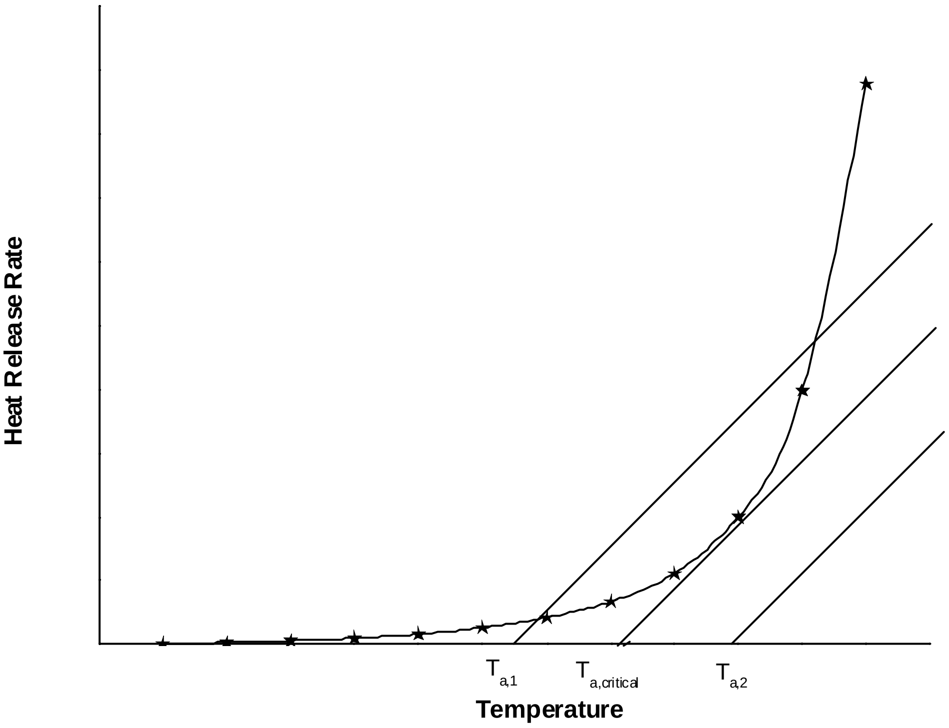
C6/52A

APPENDIX 2

Part 1

1. The nature of the CAT can be demonstrated by reference to curves showing the rates of heat production and heat loss for any given body. The way in which a chemical reaction rate varies with temperature is given by the Arrhenius expression. One constituent of that is the activation energy, which can be thought of as the threshold energy required to get the reaction going. The lower it is the faster the reaction will go particularly at low temperatures.

2. The slope of the *heat production* curve predicted by the Arrhenius expression increases rapidly as temperature increases. By contrast the rate of heat loss from a body is only a linear function of temperature i.e. it increases proportionally. Professor Gray's figure 1, reproduced below, shows, by way of figurative example, a heat production curve predicted by the Arrhenius expression together with 3 straight lines representing the rate of heat loss from a body of a given fixed size at 3 different ambient temperatures.

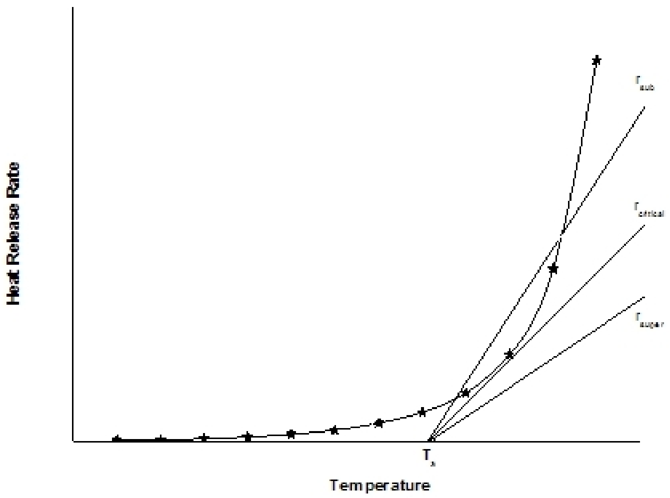


3. The intersections of the straight lines and the curve represent conditions where heat production and loss balance exactly. As can be seen, in respect of the first ambient temperature postulated (Ta.1) there comes a point (at the first intersection), when the temperature of the body is slightly above the ambient temperature, at which the rates of heat production and loss are equal and beyond which the rate of heat loss exceeds that of heat production, so that the temperature of the body will *decrease*. This lower balance point is treated as a stable point and perturbations (i.e. increases of the temperature) from it will decay as the temperature returns spontaneously to the stable point. At the second intersection, which is at the "*critical stacking temperature*", and which the body in question may reach e.g. because, although the ambient temperature remains constant the body in question started at a temperature in excess of ambient or heat is applied to it, there is a watershed above which the heat production curve continues upwards almost vertically, whilst the heat loss line continues as before and the temperature of the body runs away.

4. In the case of the second temperature postulated (Ta.critical), the (sole) intersection point, and thus the critical stacking temperature occurs at a lower temperature than is the case with Ta.1. Just beyond this point the rate of temperature rise (the excess of heat production over heat loss) will be slight until thermal runaway occurs when the rate of heat production rises vertically.

5. If the ambient temperature exceeds the CAT, as in the case of the line furthest to the right in the figure (Ta.2), there is no balance point and the only result will be explosion.

6. The slope of the heat loss is dependent on the surface area to volume ratio for the body. That ratio increases as the body gets smaller and decreases as the body gets larger. The slope of the straight line on the figure will be angled closer to the horizontal and the rate of heat loss will thus be less (at the same ambient temperature) the larger the body. This is represented in Professor Gray's figure 2.



7. Thus, for a group of packages stacked together the CAT will be considerably lower than for a single package because, although the packages as a whole may take longer to heat than the single keg, the heat generated at the centre of the group has to escape not only to the edge of the individual package but also to traverse the surrounding packages before it can become absorbed by the inert environment. As a result, as is now known, a test for the CAT value of a single body – e.g. a keg with 15 kg of material – can be misleading if that value is applied to the shipment of a large number of kegs in a container.

Part 2

1 The matters set out in this Appendix are largely derived from the first reports of Professor Gray and Mr Phillips, as further explained in oral evidence.

Heat loss

2 The heat loss from a package or group of packages will depend on the surface area of the package(s) and the ambient temperature of the surrounding air. Resistance to heat loss is twofold:

(a) the resistance within the material itself, which is characterised by the thermal conductivity of the material itself. The higher the thermal conductivity the lower the resistance to heat loss.

(b) The resistance at the wall of the package i.e. the interface of the package and the surrounding air. The thermal resistance of the material of the wall itself is usually much smaller than that occurring at the solid/air interface.

3 If the conductivity of the material is low, as is found in most cases of spontaneous ignition it is the material itself which provides the factor limiting heat transfer. This is not, however, the case with UN 1748 where significant resistance to heat loss occurs at the package/air interface.

Biot numbers

4 The *Biot number* is the quantity used to characterise the ratio of heat transfer though the package interface to heat transfer through the material itself. It describes how well heat flows into or out of the body compared to how well it flows through the body. If the number is large it means that most of the thermal resistance is *internal* i.e. comes from within the material itself such that the existence of further resistance to heat transfer outside the package would have little effect on the CAT. Packages with a large biot number are not particularly sensitive to their surroundings so that placing them in a container whose wall would have considerable resistance to heat transfer will not greatly affect their CAT.

5 If the Biot number is small the resistance to heat transfer is mainly *external* and across the package/air interface. Such packages will be sensitive to the surroundings and will have lower CATs when placed inside a container which provides further external thermal resistance. UN 1748 falls into this category.

The Semenov Condition

6 In very broad terms, Semenov's analysis addressed the situation analogous to a mass with a Biot number of zero, that is a mass with some resistance to heat flow at the boundary but no resistance to heat flow internally. The cornerstone

of his analysis was the following equation, which describes the effect on temperature of the transfer and production of heat at any point in the mass:

Rate of increase of energy in the volume associated with the temperature rise	=	Rate at which heat flows into the volume	+	Rate at which heat is produced by the chemical reaction
$\rho c\, \partial T/\partial t$	=	$-k\nabla^2 T$	+	$Q\rho Z\, exp(-E/RT)$

Temperature is represented by T and time by t. The various other parameters are as described in Table 1 below. Symbols ∂ and ∇^2 represent mathematical operators associated with rates of change.

7 When the mass is at ‘criticality’ (i.e. the condition beyond which a run-away reaction is inevitable) the rate of heat production will exactly balance the rate of heat loss at the boundary. Mathematically, this means that the left side of the equation above will become zero. Semenov established that the solution to the equation is equivalent to:

$\delta_c = Bi / (j \times e)$,

where

Bi is the body’s Biot number,
j = 1 for an infinite slab, 2 for an infinite cylinder and 3 for a sphere, and

δ_c is the value at criticality of the parameter δ, which is defined as

$$\delta = \{r^2 QZ\, exp(-E/RT_a)\} / (kRT_a^2/E).$$

In this expression, r is a characteristic dimension of the body, T_a is the temperature of the surroundings and the other parameters are physical constants or properties of the self-heating substance.

8 This set of equations defines the critical temperature above which a body with uniform temperature distribution will, given enough time, self-heat catastrophically. The use of numbers 1, 2 and 3 for ‘j’ arises from the ratio of surface area to volume for the three bodies for which the theory was first developed, namely the infinite slab, the infinite cylinder and the sphere. An infinite slab is one which has a finite thickness but whose dimensions are otherwise infinite. An infinite cylinder is one which has a finite radius but extends indefinitely axially.

9 The Semenov equations can be used to determine the critical ambient temperature for the mass. The Biot number is determined from the heat transfer coefficient at the surface of the body, the size of the body and the thermal conductivity of the substance comprising the body. Using this (and

the appropriate value of ‘j' for the shape chosen to model the actual arrangement) the parameter δ_c is calculated. The critical ambient temperature (T_a) can then be deduced using the longer equation for δ given above and inserting suitable numerical values for the size of the body (r) and the physical constants and properties in the equation. The direct applicability of the process is limited to situations where the Biot number is near zero.

The Frank-Kamenetskii Condition

10 The equation describing the net change of heat in a body (see paragraph 6 above) can also be solved for situations where the temperature within the body is not spatially uniform (as in the Semenov condition) but is determined by the diffusion of heat through the body. The simplest such situation, and the first one analysed by Frank-Kamenetskii, is where the body has an infinite Biot number (heat flows through the boundary without hindrance). The critical ambient temperature is again deduced from the term δ_c but now the term depends on the geometry of the body in question. For example, δ_c equals 2 for an infinite cylinder and 2.569 for a cube. The simple formulation of the theory is only directly applicable where the Biot number is sufficiently large for it to be approximated to infinity, which usually means greater than about 12 or 15 or 20, depending on the precision required.

11 In the case of the CH on the “Aconcagua”, the Biot number is sufficiently far from both zero and from infinity for neither of the above methods to apply without reservation.

The Barzykin equation

12 Methods of deducing values of δ_c for ‘intermediate’ Biot numbers have been established and published. For example, the Barzykin equation (or the Barzykin relationship), which Mr Phillips used in his calculations, establishes the relevant value of δ_c from the Biot number and the value of δ_c that would apply if there were an infinite Biot number, in other words the basic Frank-Kamenetskii condition described above:

$$\delta_c(actual\ Bi) = Bi/2*(\sqrt{}(Bi^2+4)-Bi)*exp((\sqrt{}(Bi^2+4)-Bi-2)/Bi)*\ \delta_c(infinite\ Bi)$$

13 The value of δ_c(actual Bi) - i.e. the value at criticality of δ of a material with its actual Biot number - may be derived as follows. Frank-Kamenetskii’s work established values for δ_c for various geometrical shapes assuming an infinite Biot number. Using the Barzykin equation and the actual Biot number for the material in question it is possible to derive the value of δ_c for a finite Biot number. From that, using the equation

$$\delta = \{r^2QZ\ exp(-E/RT_a)\ \}\ /\ (kRT_a^2/E).$$

set out in paragraph 7 above it is possible, if QZ and E/R are known, to derive the ambient temperature at critical.

Table 1

Activation energy	E
Frequency factor	Z
Heat of Reaction	Q
Specific heat	c
Thermal conductivity	k
Density.	p

APPENDIX 3

1. The expert evidence in this case came close to running out of hand. The order made for experts' reports was for three experts for each party, one each from the fields of expertise of (a) chemistry and self-heating of cargo, (b) fire and (c) heat transfer. A sequence of exchange of reports was laid down, with short supplemental reports to follow. The parties limited themselves to two experts each. In the event 14 reports were presented, in excess of the number ordered even if there had been three experts. No application was made to the Court for permission to adduce these additional reports, the need for some of which arose after the order in respect of experts was made.

2. The reading time suggested by Counsel, and made available, was two days. That was sufficient to read 13 of the 15 separate items suggested including the skeleton arguments (totalling 128 pages), the arbitration award (60 pages), 9 witness statements (three files) and the cross-examination of the Chief Engineer, together with two of the experts' reports (part of item 15). When I informed the parties on the first day of the trial what I had read I was told that it was essential that I should have read the entirety of the experts' reports before any expert evidence was called. That was probably correct.

3. The idea that it would have been possible to read and digest the totality of the 14 experts' reports, contained in eight lever arch files, and obviously the product of hours of labour, as well as the other material, in two days was fanciful. It was apparent to me, as indeed the parties were at pains to explain, that in order to endeavour to understand the expert material it would be necessary to read and re-read it more than once. Mr Bright told me that he had had to read the reports several times before beginning to understand them. Appendix 2 herein will give some indication as to why that was so.

4. Having heard the factual evidence I then adjourned the case and spent about 4 further days reading the material.

5. This is a striking example of a not uncommon phenomenon. Counsel who have been engaged in the case for what may be years and have no doubt been consulted about, or at any rate seen, the expert evidence as it develops, innocently but grossly underestimate the time needed for anyone starting from a blank sheet to read and assimilate the material. In this case the problem was exacerbated by the technicality of the material, the limited user-friendliness of some of the reports, and a degree of information overload.

6. In a case such as this it would have been desirable for the parties to have considered with the Court whether or not some form of preliminary "tutorial" would have been of assistance as contemplated by paragraph 159.j of the Long Trials Working Party Report. I found it necessary to address a number of questions in writing on the experts reports, principally to Mr Phillips because his report had usefully set out some of the ground work. He answered these helpfully and with admirable promptitude.

7. It is essential for Counsel to produce a *realistic* estimate of how long it will take a judge who has no familiarity with the underlying material to get on top of it. It may have been thought that two days was some form of maximum that could sensibly be suggested for pre-reading. If so, that was an error. The only effect of so inadequate an estimate was to delay the trial by the time necessary to grapple with the material. If it becomes apparent that the estimate is too short, the court should be informed, even if recognition of that inadequacy dawns late in the day (which it should not).

8. I should also record that, in respect of some of the reports, it was not always apparent what message was to be derived from or proposition supported by the data. A large number of figures were produced, some looking much the same as others, and some baffling to the eye, even of Professor Gray. In respect of some of them it was not clear what the lines represented, there being a large number of them in indistinguishable colours on too small a scale. Graphs were produced of data in respect of days of the voyage of the “Aconcagua” or the "CSAV Shanghai" without indicating the dates involved. Matrices of readings from probes produced a plethora of data without it being immediately apparent which data was of significance (and with the place of the probes not being identified on the document containing the results). The photographs originally produced were poor copies, although that was soon remedied.

9. The quality of the examination of the evidence and of counsel’s well referenced submissions, together with some practical assistance in the form of better and bigger copies and manuscript notations on various figures, resolved most of these problems. As a result, as they will recognise, I have adopted some of the contents of Counsel’s submissions, with amendments, as accurate summaries of the evidence. But, if the problems to which I refer had been resolved at an earlier stage the task of assimilating the material would have been both shorter and easier.