Analysis by Zimmermann & Jensen Engineering provided the following results.

- Positive material identification (PMI) indicated that weld repairs performed in 2013 were performed with materials specified for the spent slide valve.[17]
- Clearances measured with a feeler gauge indicated that the leading edges of the valve gate (referred to in the Z&J report as the "disc") were washed out and that the gap was too large to measure with the feeler gauge.[18]
- Photos of the cleaned spent slide valve gate and seat ring (Figures 23 and 24) confirmed what was seen at the site. Damage was significant to both the gate and seat ring, easily allowing catalyst to seep through the gaps from the reactor into the regenerator. Also easily allowing air to flow from the regenerator into the reactor once the catalyst above the spent slide valve was gone.

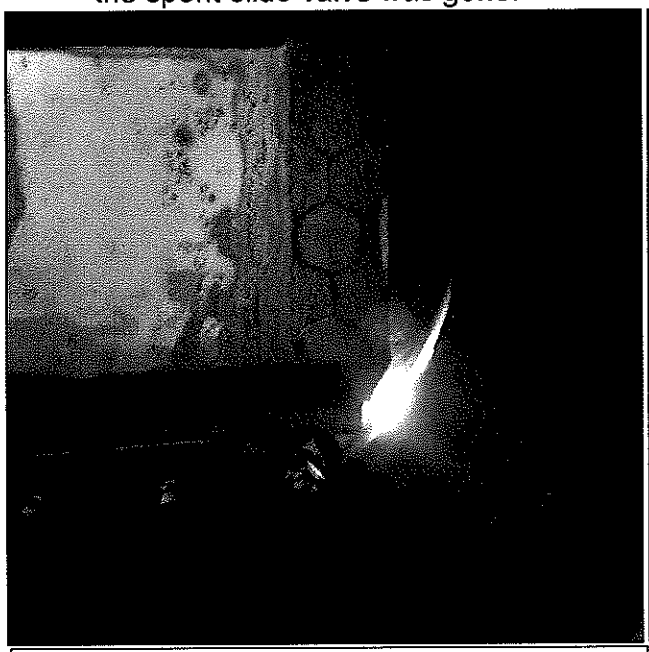

Figure 23: Light shining through the gap between the spent slide valve gate and seat ring.

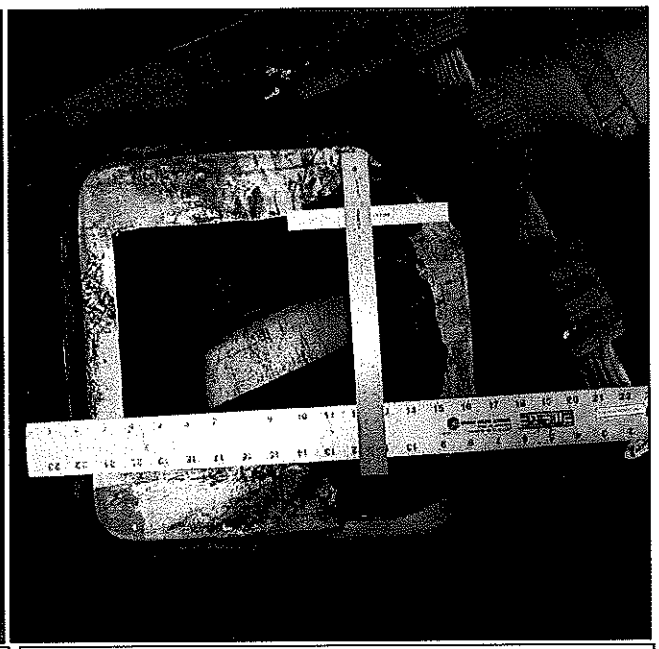

Figure 24: Damage to the spent slide valve seat ring once disassembled.

Failure to retain sufficient catalyst level during standby operations due to worn slide valves was also found in an FCCU explosion in California in 2015 that was investigated by Cal OSHA and the CSB.[19]

Absorber Materials of Construction

The absorber shells were made of American Society for Testing and Materials (ASTM) A-201 (Sponge Absorber) and A-212 (Primary Absorber) carbon-silicon steels and were installed in 1961.[20] The ASTM standard for A-212 metal production was withdrawn in 1967[21] after problems and failures of this metal occurred due to metal embrittlement.[22] Both materials were removed

[17] See "SUPERIOR013495-SUPERIOR013495 - PMI Inspection Report - Superior Spent Slide Valve 235726942_1," "SUPERIOR012532-SUPERIOR012533 - Welding Procedure Specification C-4 - 1997-12-05," and "SUPERIOR012534-SUPERIOR012535 - Welding Procedure Specification C-5 - 1997-12-05."

[18] See "SUPERIOR013492-SUPERIOR013494 - Clearance Inspection Report - Superior Spent Slide Valve 235726888_1."

[19] See CSB report of Exxon/Mobile Torrance Refinery incident.

[20] See "HUSKY000991-HUSKY000992," and "HUSKY000993-HUSKY000994." U-1 forms for the absorbers.

[21] See: https://www.astm.org/DATABASE.CART/WITHDRAWN/A212.htm

[22] See Attachment 2, ASTM A-212 Pressure Vessel Steel – A Case Against Continued Use, Dated June 20, 2011.

from the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section VIII in 1968 as being unfit for thermal cycling.[23] The following excerpt from the conclusion in Attachment 2 is particularly concerning:

> "Pressure vessels manufactured from ASTM A-212 are still in use and the re-assessment for use under Fitness-for-Service rules requires that MDMT [minimum design metal temperature] be calculated under the newer ASME Code rules. Such evaluations will render the vessels, in all likelihood, not suitable for service under their original design specifications. The use of A-212 vessels under these temperature conditions is therefore not recommended and should only be pursued through the use of extensive risk assessment and additional hazard mitigation practices, such as employing operational controls (engineering and administrative) by limiting personnel exposure to the area of probable hazard and containing the effects of such a hazard if it were to occur. The question of continued use should not be considered on the basis of need, but rather personnel safety and liability."

Metallurgical testing of pieces of the failed absorbers, performed by the OSHA Material Failure Team in October, 2018, positively identified them as A-212 (Primary Absorber) and A-201 (Sponge Absorber), and also indicated the presence of metal embrittlement (Figure 25).

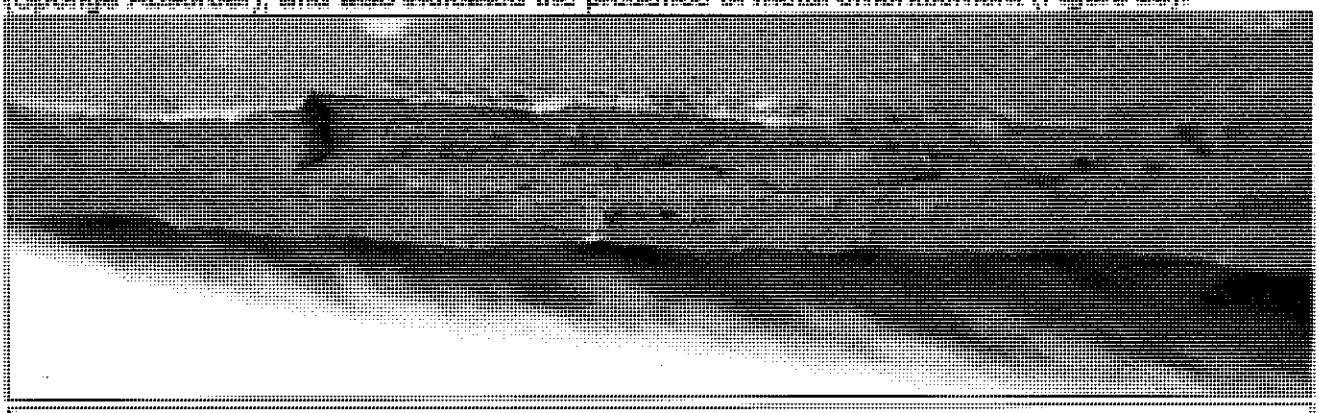

Figure 25: Metal fatigue cracking evident on the metal shell.

Chemical analysis of scale deposits on pieces of the metal (performed by Baker Hughes) identified high concentrations of sulfur and iron, suggesting the presence of iron sulfide deposits in these vessels before the explosion and fire.

The National Board Inspection Code (NBIC), requires internal inspections or complete in-service evaluation of pressure-retaining items not to exceed one-half of the estimated remaining service life of the vessel or ten years, whichever is less.[24] The NBIC further states regarding brittle fracture:

> "Determining susceptibility to brittle fracture should be required as part of the overall assessment for evaluating remaining service life or to avoid failure of the pressure-retaining item during a pressure test. In order to carry out brittle fracture assessment,

[23] See ASME BPVC 1968, Subpart C, Requirements Pertaining to Classes of Materials, pp 100-113. UCS-5(a) states: "All carbon and low-alloy steel material subject to stress due to pressure shall conform to one of the specifications given in Section II of the Code and shall be limited to those listed in Table UCS-23 except as otherwise provided in Pars. UG-10 and UG-11." ASTM A-201 (ASME SA-201) and ASTM A-212 (ASME SA-212) are not listed in the table or per Pars. UG-10 and UG-11, nor are they listed in subsequent revisions to the code.
[24] See the National Board Inspection Code, 2013, Part 2, Inspection, Section 4.4.7(a).