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# DESIGN OF COPPER SX PLANTS TO MINIMIZE STATIC AND OTHER FIRE RISKS IN THE LIGHT OF RECENT INDUSTRY FIRES

By

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## 1. INTRODUCTION

The first two commercial copper solvent extraction (CuSX) plants were small scale plants built in Arizona for Ranchers Bluebird Mine and Bagdad Copper in the USA in the late 1960s for treatment of heap leach and dump leach solutions respectively and producing 5500-6500 stpa cathode copper. These plants were followed shortly afterwards by the very much larger scale CuSX plant for ZCCM at Chingola, Zambia, for treatment of tailings leach solution and producing approximately 100,000 tpa cathode copper. Since then, CuSX plants have ultimately proliferated on a world wide basis, providing largely continuing improvements in design and seemingly ever decreasing unit capital and operating costs as plant sizes have increased from an early low of around 5,000 tpa to up to a current maximum of 168,000 tpa (185,000 stpa) at the world's currently largest electrowinning (EW) plant at Morenci, Arizona[1] or the even larger 200,000 tpa capacity plant to be built for the Spence project under development in Chile[2]. However, it would seem that somewhere along this development path of continually reducing unit capital costs that an air of complacency inadvertently crept into the design process for certain plant configurations. For plants designed prior to 2002, it would seem highly likely that the risks of fire occurrence and control may not have been adequately addressed and minimized. It is possibly only for plants designed within the last 2-3 years that fire safety issues have now been closely examined and incorporated into appropriate low risk designs.

Certainly the two recent major CuSX fires at the Olympic Dam copper-uranium mine in South Australia on 23 December 1999[3] and 21 October 2001[4] and the subsequent two smaller scale, but nevertheless equally serious, CuSX fires at copper heap leach operations at both the Metcalf plant of the Phelps Dodge Morenci copper operations in Arizona on 16 October 2003[5,6], and nearby Mariquita SX plant of Minera Maria (a subsidiary of FRISCO) in Mexico on 18 March 2004[7] have provided a wake-up call to the industry and demonstrated the need for a serious and immediate review of current CuSX design policies for fire control. Detailed reviews of fire safety by plant owners, engineering companies, risk assessment companies, diluent and reagent suppliers, specialist process consultants, insurance companies, state mining regulators, lawyers and others have already occurred to varying degrees on the plants affected by the fires, but regrettably with only limited public reporting of the findings to date. The results of these and other reviews are being applied to the design of a limited number of new plants and possibly to the retrofit of selected existing plants in order to minimize the risk of fire in selected plants. Little is known about the status of any refit on many of the older CuSX plants that may possibly still be subject to significant fire risk.

Control of static and other fire risks in CuSX plants is addressed in this paper, primarily from a historic plant design review perspective, but also drawing on literature, public domain and Freedom of Information sources on fire events at Olympic Dam and other plants where available.

The authors of this paper have a chemical engineering background and have been involved for much of their careers in the development and process design review of CuSX and USX plants for mining companies, engineering companies, third parties as well as currently being independent consultants. Their experience has extended from the earliest days of SX design and development through to recent plant designs. This paper represents an attempt to share a process-orientated knowledge base with others so that new and/or existing plant designs can be modified, where required, at minimum cost to ensure greater fire safety in the industry.

Causes of fires in CuSX plants include static electricity, inadequate piping design allowing the formation of flammable vapours and mists inside organic drain lines, and human error during maintenance work. It is interesting to note that of the four fires that have occurred since 1969 all have taken place in relatively new plants owned by both major and junior mining companies and built by both major and small engineering companies. The risks of fires would therefore appear to be independent of the level of financial or technical backing of the mine owner or the engineering company, and to be more due to a culture that has been somehow insensitive to the real risks of fire in CuSX plant design, operation and maintenance.

## 2. HISTORICAL CUSX DESIGN DEVELOPMENTS

A paper[14] presented by the authors at Alta Cu 1977 in Brisbane, Queensland, Australia, evaluated developments and trends in commercial solvent extraction mixer-settler and contactors at that time. Key process issues relevant to fire risks, not necessarily identified in the same way in the earlier paper but specified more clearly in the current paper, include:

- Evolutionary changes with time in the selection of different materials of construction for mixers, settlers and interconnecting piping, based on targeting lowest possible capital costs for handling various site liquors (some containing high chloride levels unsuitable for stainless steel materials, especially in Chile) and generally increasing pregnant liquor flow rates, including the first use of various construction materials as follows:
    - FRP-lined concrete mixer-settlers (Ranchers, Arizona, 1968).
    - FRP free standing mixer-settlers (Cyprus Johnson, Arizona, 1976).
    - PVC Lined steel mixer-settlers (Anaconda Arbiter Plant, Montana, 1974).
    - Stainless steel free standing mixer-settlers (Bagdad, Arizona, 1970 and Twin Buttes, Arizona, 1975).
    - Stainless steel lined concrete mixer-settlers (Nchanga, Zambia, 1974).
    - HDPE lined concrete mixer-settlers (Codelco, Chile, 1987)
    - FRP interconnecting piping (Ranchers 1964 and Cyprus Johnson 1976, Arizona).
    - FFRP reinforced PVC interconnecting piping, Nchanga, Zambia, 1974.
    - Stainless steel interconnecting piping (Bagdad, Arizona, 1970, and Twin Buttes, Arizona, 1975)
    - HDPE interconnecting mixer-settler piping (Inspiration, Arizona, 1979, Codelco, Chile, 1987 and Krebs SX Olympic Dam, South Australia, 1988)
- Use of plastic construction materials that were known to be flammable (HDPE lining, HDPE piping, FRP lining and FRP piping unless impregnated with a fire retardant), but were still used because HDPE, the most common material, was generally considered to be very difficult to ignite and burn, until the two recent Olympic Dam CuSX plant fires.
- Relative humidity and temperature at the site and their effects on flammability.
- Number and spacing of SX trains and whether a CuSX mixer-settler affected by fire could be scuttled, or rapidly dumped, to a safe discharge area that would not allow fire to spread back to the rest of the plant.
- Plant layout changes with time including:
    - Initially an older style above-ground mixer-settler design with the settlers being supported by a steel, concrete or FRP structure well above ground, the mixers being supported on or slightly above ground, and the active level of organic in organic holding tanks being at essentially the same elevation as the active level of the organic and/or combined phases in the mixer-settlers. *In the opinion of the authors, this design would have resulted in:*
        - *Mainly full loaded organic lines, especially if a butterfly valve were included to control pressure drop and level in the loaded organic discharge weir box, and the line entered the loaded organic tank via a bottom entry.*
        - *Minimal air entry into the loaded organic line, provided that a suitable vortex breaker was located at the organic pipe inlet and a*

    *suitable pipe sizing had been selected, but still allowing burps of air to occasionally accumulate and release back in the organic weir.*

- A subsequent “low-profile” modern mixer-settler design as pioneered by Holmes & Narver on the Cities Service Miami SX plant design in 1976, whereby in addition to shallow mixers and settlers located on ground level. a separate tank farm area containing the organic and other recirculating fluid tanks was located about 3-5 m below the ground level in an adjoining dedicated area. *In the opinion of the authors, this design would have resulted in:*
    - O*nly partly full loaded organic drain lines and high organic velocities down those lines, unless a butterfly or similar valve were included in the drain line to control pressure drop so as to hold a full line, except possibly for the final drop of organic level from the upper entry point of the loaded organic holding tank into the lower level of the loaded organic holding tank via a bottom entry organic line or its equivalent.*
    - *Possibly significant air entry into the organic line unless a suitable vortex breaker was located at the organic pipe inlet and suitable pipe sizing had been selected, but still allowing burps of air to occasionally accumulate and release in the organic weir. If the organic entry to the loaded organic holding tank was located in an open air space above the operating liquid level, possibly significant amounts of air from within the holding tank could have entered the organic discharge pipe and mixed with the free falling organic to form an emulsion on the surface and organic mist in the vapour space as the organic transferred to the holding tank.*
- Subsequent conventional mixer-settler designs involved on-ground settlers, or slightly above ground settlers supported by compacted earth fill which were initially close coupled to the loaded organic holding tank with a full operating tank level at the same organic level as that in the settler, but were later coupled to a more distant loaded organic holding tank situated in a tank farm located at a much lower operating fluid level than that in the settler. *In the opinion of the authors,* t*his design would have resulted in:*
    - *Mainly full loaded organic drain lines for the initial close coupled design.*
    - *Probably only party full loaded organic drain lines in the later tank farm designs, unless a butterfly or similar valve was included in the line to control pressure drop so as to hold a full line, except for the final drop of level from the upper entry point of the loaded organic holding tank into the lower level of the organic holding tank via a bottom entry organic line or its equivalent.*
- Air vents in the loaded organic drain lines to try to minimize air entrainment in those lines at two plants:
    - The Cyprus (formerly Anamax) Twin Buttes plant (1974), with one air vent located on the loaded organic drain line close to the entrance to the loaded organic holding tank. *This design apparently was intended to release any entrained air prior to the organic phase entering the loaded organic holding tank. The loaded organic tank ran at the same operating liquid level the adjoining settler, and was equipped for bottom entry so that settler, so that there was always a back pressure of organic in the air vent, thus preventing the ingress of air.*
    - The WMC Olympic Dam CuSX “conventional design” CuSX plants, in the 2002 fire and possibly also in the 1999 fire, at apparently two locations in each loaded organic gravity drain line for CuSX trains A and B. One air vent, the upper air vent, was located at the start of the loaded organic drain line shortly after the organic exited the

settler. The other air vent was located at the end of the loaded organic drain line near the point where the drain line entered an organic holding tank in a below ground tank farm. *These designs apparently resulted in substantial mixing of air and organic and organic mist formation in partly filled loaded organic drain lines at both the start of the line and at the end of the line.*

- Static discharge rings consisting of electrically earthed metal flanges located at regular points along the length of the HDPE organic drain lines and protruding possibly as much as 2 cm into the 630 mm ID inner flow space of the HDPE piping were apparently installed within the loaded organic drain lines at Olympic Dam to try to minimize static build up within the organic flow. *Coupled with the effects of the air vents,* this *design appears to have lead to:*
  - *Aggravated turbulence and air mixing within the loaded organic phase.*
  - *Numerous crud collection points on the immediate upstream side of the flange points along the entire length of the loaded organic drain line, which was only apparently about 60% full at maximum flow due to the large drop in elevation from the entry point to the exit point.*
  - *Organic flow velocities that were higher than the safe design levels for control of static.*
  - *Mists of air and organic plus foaming of the organic, that would appear to have led to a flash point that was much lower than the design flash point for a non-aerated organic.*
  - *Key points of high aeration within the pipe that would appear to have been vulnerable to ignition by an electrostatic discharge from a highly charged HDPE surface or the loaded organic liquid surface.*
  - *At some point during SX plant start-up and flow stabilization, a fire inside the part filled and aerated HDPE loaded organic drain pipe that was able to be sustained possibly by crud and HDPE burning at a highly aerated flange point near the discharge end of the pipe for a sufficient length of time so that the HDPE pipe walls became weakened by high temperature, collapsed by melting and subsequently ruptured to allow burning organic to escape through the molten and rapidly widening pipe void.*

- Some mixer-settlers were designed without covers in Arizona in the mid to late 1970s to secure capital cost savings, but with design provisions for adding a cover later if required (Cities Service, Arizona, 1976). Earlier plants and most, but not all, later plants included a cover as part of the original mixer-settler design and installation. *The covers were intended not only for dust control, but also for control of diluent evaporation and for containment of fire fighting foam that was designed to be rapidly applied to the organic surface to smother a fire through use of automatic fire fighting nozzles located above the top of the mixers and settlers in the more advanced fire fighting systems. The plants without settler covers were of stainless steel construction with stainless steel piping which would not have provided a supplementary flammable source of combustion throughout the plant.*
- Fire control design measures in most of the very early CuSX plants were relatively basic but effective and included:
  - Limiting organic line velocities to less than approximately 1 m/sec, for minimizing pressure drop in the lines connected to the low head pump mixers in each primary mix box and to minimize static generation in organic liquid flow.
  - Ensuring that organic lines were kept full to minimize air entrainment in the organic.

  - Use of materials of construction such as FRP with fire retardant or stainless steel for construction of mixers, settlers and interconnecting pipe lines.
  - Suitable lightning protection to ensure that lightning could not initiate an SX fire, even in an open settler.
- Static generation from organic flow and the possibility of fire occurring within the contents of an organic pipe from a static discharge did not appear to be a serious process concern in early CuSX plants.
- A fire in an electrical motor located above the organic in the primary pump mixer box or in an organic transfer pump or because of welding sparks during maintenance on an organic tank seemed to be regarded as the main area of risk in early plants where the materials of construction were essentially non-flammable.
- The flash point of the organic was considered to be high enough to avoid any real concern of fires from a low heat source such as a match. There was even the unusual demonstration of throwing a match onto the surface of the organic and noting that the match extinguished, to demonstrate that the organic was not easy to ignite.
- Even when HDPE usage for piping and tank lining became common, there appeared to be a general perception that HDPE, an organic material, was difficult to ignite. The potential consequences of unexpected ignition of HDPE were therefore not considered as seriously as they should have been in hindsight.
- CuSX plants that included low level tank farms for organic storage and recycle would appear in hindsight to have been the first CuSX plants to breach the 1 m/sec organic drain line velocity constraint for static generation, unless flow control devices were used in the loaded organic drain lines to constrain the velocity to less than 1 m/sec. If constructed of stainless steel piping, the risk of a fire within the organic drain line would have been minimal, even though the organic could still have become highly charged during its transfer down the partly empty drain line. If constructed of HDPE piping without any flow velocity controls, as would appear to have been the more common practice for plants constructed after 1988 through say 1992, the risk of fire from an electrical discharge due to static would have been much higher.
- The drawbacks to the design evolution of CuSX plants would appear to be the failure to consider at a much earlier stage of the design the application of the risk management processes used to ensure fire safety in the oil and gas, petrochemical and refining industries, where much larger volumes of highly volatile solvents are handled with much greater safety, except for the milestone disasters such as Flixborough in the UK and some similar high profile disaster events in the USA.
- The salutary and frightening conclusion to the SX plant fires has been that if the fire is not under control or isolation within the first few minutes of the outbreak that potentially the whole SX plant will be lost within the next 6-24 hours due to the size of the interconnected burning fuel sources and the intensity of the fire, no matter how many fire appliances might be available to try to control the fire.

## 3. STATIC

From initial references to static as a probable key cause of the 2nd fire at Olympic Dam[4] and also as a possibly contributing cause of the 1st fire at Olympic Dam[3] in the SA Metropolitan Fire Reports on those fires, and from the subsequent more detailed references to static in the two more detailed reports by the South Australian Mines Inspector on the same two fires, and obtained by IPDS under Freedom of Information provisions from the Department of Administrative Services of the South Australian Government, further historical as well as more recent references on static have been collected[10-13]. Relevant excerpts on static are reviewed below:

- **Designing solvent extraction plants to cut the risk of fires, Davy International Minerals and Metals Ltd, Gordon Collins et al, E/MJ December 1978[10]**
  - Pipeline Design:
    - Generation of static electricity is proportional to the flow velocity, which must be limited to safe values.
    - API 2003, ñRecommended Practice for Protection Against Ignitions Arising out of Static, Lightning and Strong Currents, ñOctober 1974 refers to 1.8 m/sec where the discharge is always below the tank liquid level.
    - A velocity of 1 m per sec is recommended for all SX piping to allow for variations at startup and during abnormal operations.
    - Piping material is also an important factor in calculating the generation of static electricity. Nonmetallic materials, fibreglass-reinforced plastic (FRP) and similar materials present more difficulty with respect to charge dissipation.
  - Grounding for static electricity discharge:
    - Grounding is an important design consideration.
    - Pipes and equipment must be adequately bonded and grounded to prevent sparking from static buildup and accidental discharge in the presence of flammable liquid or vapor.
    - FRP pipe and vessels may be covered with conducting paint to dissipate any static that collects on the outside of the pipe lines .(*IPDS comment: external conducting paint may not significantly help dissipate static collecting on the inside of the pipe or in the organic phase flowing within the pipe.*)
- **Fire Protection For Solvent Extraction Plants, What We Can Learn From Olympic Dam, Frank Rizutto, Plumbing Engineer, July 2002[11]**
  - Static Discharge As Ignition Source:
    - Fire in the 2001 Olympic Dam fire was believed from public domain reports to have originated from static discharge within the piping network.
    - Flow of a relatively non-conductive liquid through piping creates the probability of buildup of a static electrical charge in the liquid.
    - Other potential ignition sources including electrical connections, electrical cable overheating, electrical motors, sparking tools, welding, and smoking were considered much less likely than static electricity.
    - At Olympic Dam, relatively non-conductive liquid was flowing through non-conductive HDPE pipes.
    - Kerosene has about six time the ability of gasoline to generate static.
    - In the case of relatively non-conductive fluid flow through metallic piping, the static is readily discharged to ground when the piping and equipment are properly bonded and grounded.
    - In the case of non-conductive fluid flow through plastic piping, the static cannot be readily discharged and accumulates within the fluid
    - The generation of static is in itself not hazardous.
    - The real danger was said to lie in the accumulation of static because in this way energy can be stored to create a spark capable of igniting a flammable vapor-air mixture. For comparison purposes, sliding across an automobile seat was pointed out to generate up to 15 mJ, while the energy level required for ignition of a flammable liquid mist was approximately 1 mJ.
    - Sparks have been reported to be seen darting across the liquid surface of an agitation tank containing high flash point liquids.
    - Sparks can also occur above the liquid surface.

- In the case of lower flash point products in other operations (Class 1 flammable products such as gasoline), vapors at the liquid surface may be too rich (above the upper flammable limit) to ignite and static charge tends to relax as liquid settles in a vessel after filling.
- In the case of CuSX operations, when flammable vapor or flammable mist is present at the solvent surface, it is more likely to be between its lower and upper flammability limits, and solvent in the mixer-settler circuit (*or presumably in a solvent holding tank*) remains at rest long enough to relax its static charge. In this scenario, the fire triangle can be revised from:
  - Fuel + air + ignition source = fire

  to:
  - Fuel + air = fire

  since all external ignition sources will have been eliminated. The fuel itself was suggested to provide the ignition source.
- The mixture of conducting and non-conducting materials (*presumably meaning the organic liquid and piping materials*) as well as turbulence caused by the metallic fittings and changes in direction, spillage into vessels, agitation, filtering and drainage promote the generation of static in the system.
- The problem of mitigating the static charge on the liquid surface reportedly cannot be solved by attaching any number of ground wires to it. Instead it is considered necessary to reduce or eliminate static generation, volume charge or surface charge.
- The most hopeful solution was felt to lie in the development of a non-contaminating additive that would lower the resistivity of the solvent to a value where static generation would be eliminated. (*IPDS understands from other sources that such an additive may have been found and patented by WMC for Olympic Dam.*)
- Mechanical measures to reduce the generation of static include:
  - Non-centrifugal transfer pumps that are designed to create the least turbulence.
  - Pressure reduction within the piping to the lowest values for efficient liquid transfer where possible.
  - Fluid velocity reduction, noting that the same volumetric flow rate of pumped liquid travels at a lesser velocity through a larger diameter pipe. (*IPDS comment: reduction of flow velocity in non-pumped or gravity flow lines will require a suitable control valve at the end of the line to keep the pipes full of liquid and to minimize air collection along as much of the pipe length as possible*)
  - Elimination or reduction of restrictions in the piping system that cause turbulence as much as possible. (*IPDS comment: this requirement would appear to include the elimination of multiple metallic static rings in piping, such as those used at Olympic Dam.*)
  - Selection of higher radius bends in piping runs.
  - Submergence of tank infeed nozzles. Avoidance of splash filling. The velocity of flow and the method of introducing the flow into a vessel should be such as to keep from stirring up water or other aqueous material which increase the ability of the solvent to generate static
  - Bonding and grounding of all metallic elements in the piping system, such as pumps and tanks, was considered to be a prerequisite to a program of static mitigation in the SX area.

- The additional capital cost of suitable stainless steel (*or presumably other appropriate piping materials such as FRP with carbon and fire retardant impregnation*) over (*current HDPE)* plastic could well be justified in light of heavy dollar losses associated with fires in (*HDPE*) piping and equipment.
- Static electricity should not be regarded as the cause of the fire. Rather the cause should be considered to be the condition that led to the formation of a flammable vapor concentration or flammable mist within or around the piping or equipment where a static spark was likely to occur.
- Static-induced explosions and fire in flammable vapours and mists have reportedly even been initiated in non-CuSX plants (*at flanges or in vessels)* by operators who had previously removed a piece of clothing or descended a stairway while holding onto a plastic-covered handrail. The spark sequence and spark control solutions were suggested to include:
    - The wearer of insulating footwear acquires a charge, and a spark jumps from a hand-held tool to the open pipe or vessel allowing a flammable vapor or mist to be ignited.
    - Such sources of static-induced sparks cannot be entirely controlled, but the formation of a flammable mixture in air can be controlled.
    - It was considered to be better to shut off the pressure in a leaking solvent line and eliminate the flammable mist before tightening loose flange bolting to stop the leak.
- Specific recommendation on static control for new or upgraded facilities were noted to be:
    - Assessment of the piping network for causes of static build-up and methods of mitigating static charge in piping and equipment.
    - Implementation of solutions to reduce the volume of ignitable vapours present during normal and upset conditions.
    - Provision of electrical earthing (grounding) straps for grounding mechanical equipment and tanks.
- Other sections of the Rizutto paper covered important additional topics such as:
    - Flash point and the fire triangle.
    - Mechanical failure as contributing factor.
    - Vessels and tanks.
    - Piping.
    - Maintenance procedures for risk reduction.
    - Fire prevention and plant security.
    - Fire detection and suppression in SX units.
    - The Olympic Dam fires- what worked and what didn't.
    - Fire protection for new facilities and upgrading of existing plants.
    - Summary and conclusions.
    - References.

- **Electrostatic Hazards In Solvent Extraction Plants, Peter Haig and Jodie Maxwell, Shell Chemicals and Theo Koenen, Shell Engineering Ltd, ALTA Cu 2003, Perth, Australia [12]**
  This key paper provides a diluent supplier viewpoint of the risks caused by static generation in CuSX plants, based on experience with hydrocarbons in the oil and gas industry. It highlights the flammability of and ignitability of CuSX diluents compared with other solvents, the mechanics of electrostatic charging of the SX solvent, how charge accumulates, the different types of electrostatic discharges that can occur and the applicability of these issues to improvements to the safe design and operation of solvent extraction plants.

  Key points include:
  - The need for a heightened awareness of electrostatic hazards in CuSX plant design, management and operation to avoid major fire risk.
  - The occurrence of many serious accidents in the oil and gas industry due to electrostatic discharge during large scale hydrocarbon processing and handling.
  - The occurrence of numerous fatalities due to electrostatic discharge during filling of cars with gasoline at service stations in the USA (comment by presenter of the Shell paper at the ALTA 2003 conference)
  - Insufficient attention given in past CuSX plant designs to the hydrocarbon handling risks through a tendency to think of the plants as simple aqueous handling plants without major fire risks.
  - The heightened danger of electrostatic hazard in CuSX plants due to:
    - The extensive use in many CuSX plants of non-conducting HDPE, a flammable material with no fire resistance, for:
      - pipeline transport of solvent
      - liners of mixer tanks that mix solvent and aqueous phases
      - liners of settlers that separate solvent and aqueous phases.
    - The low conductivity of CuSX solvents as opposed to USX solvents.
    - Significant electrical charge generation as low conductivity solvent flows at high velocities over non-conducting surfaces.
    - Electrical charge accumulation in the solvent during pipeline flow.
    - Production of high electric field strengths and potentials of sufficient levels to result in electrical breakdown of the air in the pipe or tank.
    - Ignition of the solvent or solvent vapour where the discharge energy is high enough and the vapour is within upper and lower flammability limits.
    - The little know fact that potential ignition of solvent mists (suspended droplets in air) or solvent foams (aerated solvent) can occur at up to 20C below the flashpoint of solvent by itself (normally approximately 80C) if conditions are appropriate.
    - Mists and sprays being generated when hydrocarbons moved through high shear pumps and mixers and other turbulence creating devices are exposed to air.
  - High flash point diluents used in CuSX plants having a typical volume percentage range in air of:
    - LFL (lower flash limit) of approx 0.7 vol% in air
    - UFL (upper flash limit) of approx 7 vol% in air.
  - A saturated vapour composition of below the LFL being too dilute to be flammable and of above the UFL also being too rich to be flammable.
  - The impossibility of combustion if the concentration of oxygen in the atmosphere is too low, such as achieved by:
    - keeping a CuSX organic line full of solvent during operations

  - inerting a vapour space with an inert gas such as nitrogen of carbon dioxide.
- An MIE (Minimum Ignition Energy) capable of igniting most hydrocarbons including CuSX organics of only 0.2 mJ versus the much higher spark energy of 40 mJ received when "zapped" from your car on a dry day.
- Electrical potentials of up to 20kV measured in CuSX plants where there is high shear mixing and pumping of low conductivity organic through insulating HDPE pipes. The current carried by the organic leaving the pipe is known as the "streaming current".
- Electrostatic charges are generated by:
  - Relative movements of differing liquids such as aqueous and organic when agitated (The organic charges are left fixed in the bulk phase after settling of the aqueous)
  - Atomization or misting when an organic liquid is separated into fine drops, due to poor design of the piping system or excessive agitation.
  - Splash filling of the organic in loaded organic tanks.
- Hazardous potentials can be reached by all CuSX diluents through simply passing through a micro filter.
- Ignition of a flammable atmosphere by internal electrostatic discharge can take the form of three types of discharges:
  - Spark discharges that occur when:
    - The spark energy exceeds the MIE
    - The voltage exceeds 1kV for organic (e.g. a potential of more than 4 kV would be sufficient to cause an incentive spark from a 600mm internal diameter HDPE pipe where the stored electrostatic energy was 0.2 mJ).
  - Glow coronas from a single sharp conductor that has been raised to a high potential, but only for highly sensitive materials such as hydrogen and not for CuSX organic.
  - Brush discharge between blunt conducting electrodes and insulating materials such as solids or low conductivity liquids such as CuSX organic and characterized by:
    - Energies as high as 4 mJ
    - Ability to ignite most gases and vapours.
- Typical CuSX organic handling operations that can give rise to electrostatic ignitions include:
  - Filling tanks and containers such as sample buckets.
  - Circulating organic through partly filled tanks.
  - Road tanker deliveries of diluent.
  - Agitation of two phase mixture.
  - Settling of two phase mixtures.
  - Crystallization from low conductivity liquids such as loaded organic.
  - Passing organic through insulated pipes.
  - Passing organic through flexible hoses.
  - Filtering organic.
- Typical conductivities of fresh lab CuSX organics containing 0-10 % oxime or similar reagents are low and of the order of 20-30 pS/m, with a relaxation time of 150-200 seconds, versus high conductivities of the order of >200000 pS/m for USX diluents containing 5% tertiary amine.
- The addition of SDAs (static dissipating additives) to increase conductivity, as used for diesel and kerosene, has yet to be successfully applied for CuSX diluents due potential detrimental properties in CuSX plants for commonly know SDAs.
- Piping and lining:

- Shell recommends against use of non-conductive pipes and non-conductive lined settlers such as HDPE due to accumulation of static charge and the lack of dissipation of that charge.
- Shell recommends:
  - Extra precautions to be taken if the piping and lining are made of HDPE including:
    - Earthed stainless steel grid to be applied in the loaded organic tank.
    - Flange earthing connections to be made in parallel, not in series, with a continuity of <10 ohms and checked at least 6 monthly.
  - Tanks to contain:
    - conductive metal plates to the highest liquid level.
    - metal plates to be bonded and ground to earth.
    - metal plate surface area to be not less than 512 $cm^2$ per 1000 litres (1 $m^3$) of organic.
    - liquid not more than 2m distant from the nearest immersed part of the earthed metal plates.
    - incoming fill line discharge velocity not exceeding 1m/sec.
    - residence time of at least 2minutes for static dissipation.
    - fill pipes with a large diameter outlet that was directed to minimize turbulence, to discharge near the bottom of the tank, submerged to a depth of not less than 500mm of twice the ID of the pipe and not disturbing the water in the bottom of the tank.
    - spark promoters that have been grounded or else removed.
    - all conductive tank components that are grounded.
    - no conductive surface skimmers if metal plates are absent.
    - conductive material (e.g. stainless steel or conductive GRP) that lines the walls and is grounded.
  - Mixer-settlers to include:
    - All of the above provisions for tanks.
    - Avoidance of excessive agitation of aqueous with organic.
    - Where mixer-settler are lined with non-conductive material:
      - Conductive plates <u>just below the liquid surface.</u>
      - Consideration of earthed stainless steel picket fences as an effective measure for dispensing some of the charge.
  - Piping materials to incorporate:
    - Piping systems made of conducting materials such as stainless steel or conductive GRP or similar conductive materials.
    - **Lines filled with organic to avoid formation of a potentially flammable atmosphere where there are vapour spaces**
    - Avoidance of flow through filters and screens where possible.

            - Liquid flow velocity such that $V^2d$ shall not exceed 0.64 (where V= flow velocity in metre/sec and d = pipe diameter in metre).
            - Relaxation sections in non-conductive piping by insertion of a suitable length of earthed (enlarged diameter) metal pipe of length determined from:
                - l/V = (3x18)в

              where l = length of relaxation section in metres, V = flow velocity in section in metres/second and в = liquid conductivity in picoSiemens per metre (typically 30 pS/m in CuSX organics).
            - Relaxation section to include:
                - construction and connection to minimize organic turbulence within the section .
                - location along organic piping line:
                    - close to organic receiving tank
                    - downstream of any filters and coalescers.
            - All electrically isolated sections of metallic piping, valves etc to be bonded and grounded to earth.
        - Organic pumps to include:
            - Double mechanical seals with barrier liquid and seal supporting system.
            - No belt driven equipment operating above open sumps that could provide an electrostatic discharge from friction on the belt to ignite heavier than air vapours in the sump .
            - Direct drives only when operating above open sumps.
        - All solvent extraction plants to be audited:
            - to ascertain hazardous areas (Zones 0, 1 or 2).
            - to ensure that only electrical equipment that is rated for the respective zones is used in each zone.
        - Clothing, gloves and footwear to be carefully selected such that:
            - Clothing has a surface resistance of less than 5 $x10^{12}$ŋ including:
                - Use of fibres such as cotton, flax and linen if the relative humidity is above 65%.
                - Avoidance of use of synthetic materials unless specially treated and regularly retreated.
            - Or, clothing includes conductive fibres in the fabrics.
            - Clothing, gloves and footwear is either conductive or anti-static, where there is an ignition risk.
        - Conductive surfaces such as metal grid flooring to be kept clean from insulating deposits where there is an ignition risk
    - The following mechanism of static charging and ignition of flammable atmosphere by personnel:
        - Mechanisms for charging the human body include:
            - Walking on an insulated floor .
            - Cleaning an insulated object by rubbing.
            - Contacting another charged object
            - Induction in the vicinity of another charged object.
            - Sliding off an insulated seat.

        - Removing clothing especially when contaminated with organic.
      - A person that is charged and sufficiently insulated:
        - Will almost inevitably produce a spark when approaching an earthed object.
        - Can generate a potential of higher than 30kV.
        - Can store a charge that is as high as 90 mJ.
        - Can produce an incendive spark.
      - Ignitions will be produced by sparks from people when:
        - A flammable atmosphere is present.
        - There is a mechanism for generating charge on people.
        - People have a high resistance to earth (i.e. are electrically insulated) so that charge accumulates.
    - Risk management practices similar to those adopted in the oil and gas industry were expected to allow safe continued operation of CuSX plants with little or no risk to employees of the company if the risks were properly understood.
    - Actions recommended by Shell for safe CuSX plant operation included:
      - Consultation with relevant national and international regulatory requirements.
      - Ascertain the conductivity and electrical potential of the CuSX plant.
      - Review the materials of construction of the plant.
      - Audit to assess the hazardous areas of the plant.
      - Perform a "Risk Assessment Audit" to identify hazards such as hazardous ratings of electrical equipment.
      - Issue staff with appropriate clothing and footwear.
      - Maintain continual vigilance to the possibility of static build up and discharge.

**What sparks danger in solvent extraction, Graham Hearn, Mining Magazine, pg 32, March 2005[13]**

This more recent paper, based on experience gained from a review of the influence of static in the Olympic Dam fire, raises further points on risks and the evaluation of static electricity in SX plants and provides additional advice on how the causes of static can be avoided. Specific points include:

- With the correct approach, risks presented by static electricity can be quantified and controlled.
- Five general conditions are necessary for an electrostatic ignition to be present:
    - Presence of a sensitive flammable atmosphere
    - Generation of electrostatic charge
    - Accumulation of charge
    - Electrostatic discharge
    - Sufficient discharge energy.

Flammable atmospheres:

- An electrostatic discharge (ESD) is a low-energy ignition source and may produce only a few millijoules of energy (one millionth of the energy of a burning match).
- For ignition by an electrostatic hazard, it is only necessary to restrict investigation of flammable atmospheres to those sensitive enough to be ignited by electrostatic discharge, or usually flammable gases, solvent vapours and aerosols for SX plants.
- SX operations take place at temperatures well below the diluent flashpoint of about 80C and the vapour concentrations within the plant will therefore never reach the lower explosive limit.

- Foaming (fine droplets in air) of the solvent surface will however provide a sensitive atmosphere at normal plant operating temperatures and the solvent becomes sensitive to ignition at below the flash point.
- Foaming kerosene surface can be ignited with a spark energy below 10 mJ at 30C and below 1 mJ at 65C, both of which conditions have been observed in SX plants.

Electrostatic ignition:

- A fire caused by static energy is the result of a chain of events.
- The diluent and extractant in CuSX plants can have low electrical conductivity of the order of 1-10 pS/m for virgin diluent, 50-500 pS/m for typical organic process liquids.
- Studies for Olympic Dam by Wolfson Electrostatics have shown that the conductivity range producing maximum electrostatic activity in fuel flow through plastic pipes is 1-200pS/m, particularly at high speeds through long pipe runs.
- The level of charging in the organic is increased by:
    - Pipeline features causing by turbulence such as elbows and pipe constrictions.
    - Presence of an immiscible phase such as water droplets.
- Electrostatic charges will accumulate or dissipate depending on the conductivity of the liquid and the vessel of piping.
- Concrete, aqueous liquids and metals can be considered conductive in electrostatic terms.
- Polymers such as HDPE, glass fibre (GRP, FRP) and organic solvent may retain electrostatic charge for many minutes or even hours
- Electrostatic charges can accumulate on insulating surfaces such as plastics and also on ungrounded conductors, and both these situations can be equally hazardous.
- One example of an ungrounded conductor is a metal valve in an HDPE pipe.
- After static has accumulated to a certain level an ESD can occur.
- Two distinct types of ESD may be encountered in SX plants:
    - Spark discharge:
        - Responsible for most industrial fires and explosions caused by static electricity.
        - Occur from conductive objects such as ungrounded metal fixtures and even personnel.
        - Typically 1-100 mJ energy
    - Brush discharge:
        - Occur from charged non-conductive surfaces such as highly charged plastic pipes.
        - May occur from the surface of a highly charged organic solvent
        - Maximum 4 mJ.
- Work at Southampton University has shown that both types of ESD are capable of igniting SX organics at temperatures well below the flash point, provided that certain conditions are satisfied.

Hazard Evaluation:

- The five conditions necessary for ESD hazard in CuSX plants are considered by Wolfson Electrostatics to most likely to occur in plants like the CuSX plants that were destroyed at Olympic Dam :
    - Within or around plastic (e.g. HDPE) pipes carrying organic solvent
        - Including gravity fed lines that may contain foaming surfaces and air in the presence of highly charged HDPE surfaces.
        - At small leaks in pressurized lines that may produce a most of solvent vulnerable to ESD at plant operating temperatures.
    - Possibly within HDPE-lined tanks.
- The ES activity in CuSX plants varies from one mine to another with the level of hazard depending on materials used, process parameters and plant layout.

- An ES safety audit will determine whether any measures are needed to lower or maintain the level of risk, including:
  - Monitoring the ES properties of the solvent and the static potentials at key points within the process.
  - Essential checking of the grounding of all metal work including:
    - Metallic components within plastic pipe, noting that metallic valves that have internal electrically insulated parts that may cause sparking.
    - The adequacy of existing provisions for relaxing charge from the organic surface of HDPE or other non-conducting lined tanks, noting that calculations based on liquid conductivity can be used to determine measures to be adopted.
  - Providing guidelines for implementation of key parameters such as:
    - Organic flow velocity.
    - Grounding maintenance procedures.
  - Identification of possible further safety improvement measures.

**Investigation of Copper-Uranium Solvent Extraction Plant Fire at Olympic Dam- 21/10/2001, MA Wilson, Inspector of Mines, July 2002[9]**

This extensive South Australian State Government Department Report, obtained under Freedom of Information, provides an extensive review of virtually all aspects associated with the Inspector of Minesôinvestigation of the 2001 CuSX fire at Olympic Dam. Specific findings of the report of relevance to static electricity, crud presence, crud fire test, internal pipe conditions prior to fire, weather conditions, plant redesign recommendations of Shell, Hazop studies, other SX designs, Factory Mutual Global loss prevention, misting of solvent, fire consumable and factors and fire damage include the following:

- The direct cause of the fire was not known with absolute certainty
- The fire was believed to be due to static electricity igniting:
  - Flammable or combustible hydrocarbons within a deposit of crud, or
  - Misting and/or vaporized organic in the pipe and then crud

  within an HDPE pre-scrub loaded organic drain line at a point about 10 m from the discharge end into an HDPE-lined loaded solvent (recirculation) tank.
- The loaded solvent tank was located under gravity feed at level in a below-ground tank farm well below the level of the organic in the organic weir of the mixer-settlers.
- The crud was apparently deposited on the circumference of metal flanges used to try to control static at uniform intervals down the length of the loaded organic drain line.
- HDPE piping had been selected for use throughout most of the SX plant rather than stainless steel because of its high acid and chloride resistance and low initial installation cost, rather than stainless steel which was used in limited sections but was expected to be subject to corrosion.
- HDPE piping is a combustible solid that will melt and flow in a fire situation
- The burning HDPE pipe just ahead of the loaded solvent tank allowed organic to fuel:
  - the fire on the ground and to spread away from the pipe rack into the tank farm below
  - the fire burning within the HDPE piping on the pipe rack back along the pipe rack towards the mixer-settlers and other upstream equipment .
- The selection of HDPE in the first place by WMC was reported to be based on a comment in a report by an engineering company that ñit would be virtually impossible to set the pipe alightò

- The proposed future use of FRP as a replacement of HDPE for organic piping for the future SX plant rebuild was supported by its fire resistance behaviour at Olympic Dam including:
    - FRP piping used for inlets to the main solvent pumps and protected by sprinklers survived the fire.
    - FRP does not soften like HDPE at relatively low temperatures of around 90C.
    - FRP under sprinkler protection did not add to the fuel load of the fire.
    - FRP could be made conductive with addition of carbon and fire resistant with use of antimony.
    - FRP was apparently as durable to abrasion as stainless steel.
- 8,000 metres of earth strapping that was connected to every piece of structural steel, organic bearing HDPE piping and organic pumps was grounded to earth before the 2001 fire.
- The HDPE loaded organic lines, both pre-scrub and post-scrub, were found by testing by WMC after the 1999 fire rebuild to have static build up on the outside of the lines, with most build up occurring on the pre-scrub lines (the pre-scrub lines were the lines in which the 2001 fire started).
- The static build up was apparently attempted to be rectified by using conductive paint and bandit straps at 600-mm centres along the length, adjacent to the bend and fall in the 630mm ID HDPE pipes that had the higher static voltages.
- The static voltages were apparently considered insufficient by experts to start a fire in the solvent by static discharge from the external surface of the HDPE solvent lines, although evidence elsewhere is contradictory.
- Wolfson Electrosotatics, an expert static consultant to WMC, reportedly showed that in smaller diameter pipes that the capacitive effect of metal around plastic pipe builds up the static charge and can lead to audible brush type discharges. However no explosive type sounds were reported as having been heard by any plant operator.
- Static electricity is generated in the diluent used in the organic in the CuSX plant but not in the same diluent used in USX plant, due to the addition of modifiers to the USX organic.
- Specific CuSX plant organic phase conductivities were reported to be:
    - 60 pS/m for pre-scrubbed loaded solvent (optimum for maximum static generation).
    - At levels that were well away from optimum static generation for other organic phases including:
        - either ñnon-conductiveò(24 pS/m) so that not much static is generated
        - or else sufficiently conductive (380 pS/m) for the static to be dissipated by relaxation of solvent in the organic tanks.
- AS/NZS Standard 1020:1955 Control of undesirable static electricity. The conditions necessary for static to create fire or explosion and the measures required to minimize static are identified, including the following points noted in the Mines Inspector Report:
    - The high probability of static generation between the following parts of systems conveying liquids and earth objects:
        - Electrically isolated parts, which become charged by flowing liquids e.g. pipes and fittings.
        - Electrically isolated parts which become charged by induction e.g. floating objects.
        - Charged liquid.
    - Increase in charge generation without a significant change in conductivity due to dissolved general contaminants and inclusions.

- Substantial increase in tendency for charge generation due to entrained water in refined and unrefined oil products.
- Static generation increasing with pipe diameter for constant flow and with liquid velocity for constant diameter.
- The unreliability of depending on earthing and bonding for dissipating static charges from non-conducting liquids, except where proven safe by long standing experience or substantial experimentation.
- Maximum flows for non-conductive hydrocarbons of 1 m/sec for a 600 mm ID pipe (versus an indicative average 1.5 m/sec for the apparently 2/3 full organic drain pipe, excluding acceleration near the open end into the organic holding tank).
- The presence of all conditions necessary for the development of problem levels of static in the loaded organic drain lines in the plant that caught fire in 2001.

- In an ironic twist and to show just how easy it is to be potentially misled by the risk of static electricity in any CuSX plant, apparently just 11 days before the CuSX fire in 2001 at Olympic Dam, a Wolfson Electrostatic expert is reported to have advised WMC by conference phone call in regards to a review of the about to be commissioned new CuSX plant that:
  - There was no risk of static igniting the organic liquid or the vapour at normal operating conditions (45C), due to the fact that:
    - normal operating  conditions would not generate flammable levels of vapour (as opposed to mist, which was apparently subsequently defined after the fire to be highly flammable by Wolfson Electrostatics).
    - there has been no record of static electricity igniting a liquid where the flash point is in excess of normal room temperature.
  - Static discharges, probably brush discharges, were possible within partially full organic pipes.
  - Static generation was temperature dependent.
  - Conductivity additives to the organic, of the ppm level, should be considered to prevent static.
  - Steel pipes could generate more charge than plastic pipe.
  - FRP materials of construction would be expected to have minimal risk of fire in the proposed new CuSX plant.
- Wolfson also advised that CuSX diluent at conductivity levels or around 50 pS/m had the greatest electrostatic potential and hence the greatest risk of fire when measuring the potential in an electrofusion coupling test arrangement. The maximum electrostatic potentials were as high as plus 1-1.5 kV and minus 2.0-2.5 kV.
- Similar conductivity measurements of solvent with copper in solution were reported by the Mines Inspector to have been measured by Shell International (30 pS/m), WMC (50 pS/m) and by the Ian Wark Institute on a pre-scrub loaded organic sample taken by the Mines Inspector from extraction mixer-settler ǐES1ò(60 pS/m).
- AS 1020 Appendix B 1 was reported by the Mines Inspector to show that the Olympic Dam diluent, Shellsol 2046, has a vapour composition that was well below the lower flammability limit at normal plant operating conditions of 45C.

**Crud presence:**

- Crud, a term known to many, is the term used loosely to refer to a non-coalescing dispersion of organic, aqueous, solids and/or air that forms in mixer-settlers, and is present in most plants to varying degrees.
- Crud build up would appear to have occurred over an unknown period of time at the turbulence zone of the earthing annulus ring at the flange joints of the HDPE loaded organic line, with an estimate by the Mines Inspector that possibly as little as 1 kg in weight would have been all that was necessary to sustain a fire, once ignited. In a separate report, the SAMFS Investigator for

the second fire also indicates very convincingly that crud adhering to the HDPE pipe surface was most likely a key fuel source for the fire, once ignited by a spark.
- The crud at Olympic Dam that forms between the interface of the solvent and the aqueous phases in the mixer-settlers leaves in the pre-scrub loaded solvent and precipitates out on the loaded organic settler weir was sampled and analyzed by the Mines Inspector. The assay indicated sulphate 38%, calcium 14%, silica 12%, iron 7%, and cerium less than 1%.
- The crud was referred to as jarosite, with colours of pale yellow, yellowish brown, brown, yellow ochre and yellow brown. Chemical formulae was said to be $KFe_33(SO4)_2(OH)_6$ and crystal type generally minute rhombohedral crystals
- The crud that built up behind the annular earthing rings in the loaded organic drain line was an orange brown solid, for which the colour was accentuated when soaked in organic for the fire test by SAMFS.

**Crud fire test:**
- A test was carried out on the burning of crud on a tray just inside the open end of a horizontal HDPE pipe section located in a fire test area at the Olympic Dam site by the South Australian Metropolitan Fire Services (SAMFS).
- One end of the pipe was blocked off.
- The crud was ignited
- After about one minute the burning crud had ignited the inside of the HDPE pipe as a small localized burning area, with little smoke evident and suggesting that any internal burning would not have been evident in the loaded organic tank or via the breather pipe near the discharge end of the organic drain line.
- The pipe continued to burn internally and was considered to have the potential to completely burn through the pipe from the inside, even though the test was not continued for long enough to do this.
- The pipe was also ignited and burnt fiercely on the outside at the same time as it was burning on the inside. The inside fire continued despite the strong competition for oxygen from the external fire.
- The externally burning HDPE fire produced molten HDPE drops which fell from the outside of the pipe as small fiery bombs, as described by a witness to the CuSX plant fire.

**Internal pipe conditions prior to fire:**
- The 630 mm HDPE loaded organic drain line pipes were expected by the Mines Inspector to be up to 2/3 full of liquid and 1/3 full of air, vapour and mist.
- The air space above the organic was considered to be sufficient to permit air flow and combustion.
- There was considered to be a possibility that a series of fires may have occurred in the pre-scrub loaded organic drain line that eventually led to the drain line failing and allowing the fire to spread externally.
- Adjoining organic drain lines were empty due to Train B being shut down since mid afternoon 18 October, although IPDS understands that there may have been several intermittent but unsuccessful efforts to commence flow in Train B on 20 October.
- Train A, the train in which the fire occurred, had been shut down since 18 October and was started up on 20 October but the flow had apparently not yet stabilized at the time of the fire.
- Trains A and B were both shut down for 36 hours on 18t$^{h}$ and 19$^{th}$ October and the loaded organic drain lines would have been empty for a period that might conceivably have allowed a small fire to burn for a considerable period before plant startup.

**Weather conditions:**

- The HDPE piping in the area of the fire initiation was covered by the cable rack and would not have been heated to the surface temperature of 70-80C that would have occurred if it had been empty and in direct sun in summer.
- Organic temperature was normally around 45C.
- The temperature on the day of the fire was about 25C at 12 noon and was considered unlikely to have been a contributing cause to the fire.

**Plant Redesign – Shell Services International**

In commenting on the limited changes that had occurred to the CuSX plant design for the rebuild after fire No 1 and prior to fire No 2, Shell International had a number of propitious comments and recommendations of 10 January 2000 which were unfortunately not addressed in the rebuild prior to the fire of 21 October 2001:

- HDPE piping tensile characteristics affected adversely by solvents, by temperature above 60C and by the absence of any barrier against a heat source touching the pipe.
- Escalation of the fire due to collapsing HDPE piping.
- Plant should not have been rebuilt largely as it was but should have had its design basis reviewed in the light of the fire investigation, including:
  - Suitable piping materials of construction specification.
  - Reduction or elimination of continuous solvent release from the solvent air vents in the loaded organic drain lines.
  - Location of rotating equipment and installation of secondary shaft seals.
  - Fire system design integrity.
  - Emergency shut down and isolation.
  - Inadequacy of fire separation distances.
  - Potential impedance of fire fighting by the large fire size.
  - Inadequate fire protection systems in the bunded areas around mixer-settlers and in the dump pond.
  - Inadequate cooling water back-up if the primary fire protection system failed to activate.

**Hazop Studies:**

- Hazop studies by an external consultant were conducted in 1997 (30% and 70% design points) and again in 2000.
- Such studies were considered to be weak at addressing multiple mode failures and strategic design weaknesses, according to an independent consultant, Risk and Reliability Associates.
- A Hazop recommendation for replacement of HDPE piping by stainless for pipelines traversing from the mixer-settler area of the tank farm was not adopted due to high cost and high corrosion concerns.

**Other SX plant designs:**

- 20 of the largest international SX plant designs reviewed by WMC were found to have no USX plant in series with the CuSX plant. but to have the following common features in many cases:
  - HDPE piping and tankage
  - Concrete tanks
  - Bonded roofing
  - No static precautions.

**Factory Mutual Global, Loss Prevention:**

- A 120 page guideline covering data sheets for mining and ore processing facilities, revised January 2000, includes a solvent extraction section which provides the following salient recommendations:
  - Use of FRP tanks instead of thermoplastic such as polypropylene due to softening and premature failure of thermoplastics under fire exposure.

    - Location of flammable or combustible solvent outdoors in a diked area.
    - Emergency drainage from curbed areas handling or storing solvents to run to a safe location with sizing and capacity based on guidelines provided by Factory Mutual .
    - Use of antimony trioxide for fire retardant for plastic equipment and liners where plastic is required to be used.

**Misting of Solvent:**

- The HDPE gravity drain return pipes to the pre-scrub and post-scrub loaded organic CuSX tanks were reportedly discharged below the fluid level in these tanks.
- Misting was not observable within the inside of HDPE pipe, but if it occurred it was expected by the Mines Inspector to have most likely occurred as a result of major turbulence generated at the elbow bend and corresponding 1.25 metre drop in pipe elevation at 10 metres from the discharge point into the two loaded organic tanks and then potentially dispersed within the vapour space in the partly filled pipe up to a few metres away from the discharge point.
- It was suggested that misting may have initiated and caused the fire to spread to the crud at the flange point in the drain line but there is no proof for such a scenario.
- The Mines Inspector report notes that an earlier report in February 1999 by Shell International noted the importance and risk of mist formation, pointing out that fine mist of Shellsol 2046 may ignite at temperatures below its flashpoint, due to the high surface area and mixing with oxygen.
- Unfortunately the potential interaction of the misting hazard within the HDPE drain line and internal sparking due to static electricity discharge within the same drain line was not considered a potential hazard at the time.

**Fire Consumables and Factors:**

- The fire impact was adversely affected by wind direction.
- Approximately 60 tonnes of HDPE piping and tank farm lining were consumed.
- Several hundred tonnes (thousand litres) of organic, principally Shellsol 2046, representing about 30% of the organic in the CuSX plant were consumed.
- An eye witness observed the start of the fire.
- The fire commenced at approx 12:15 pm, was nearly out but flared up with a tank rupture at 3.30 pm and was ultimately burnt out at approx. 11.00pm.
- More foam was activated on non-critical areas than was desirable and foam supplies ran low early on.
- The electric fire pump did not initially kick in as expected, but suffered a 4-5 minute delay.
- Fire reached the end of the pipe rack about 25 minutes after the fire first burst through the HDPE organic drain line.
- In the earlier 1999 fire, the automatic fire detection and related suppression systems were reported to be basically all off line within 2 minutes of the start of the fire, indicating that all automatic control systems were effectively useless within a very short time after the start of the fire. The fire was effectively unstoppable until all fuel sources accessible to the fire had been consumed.

**Fire Damage:**

- Severe damage to:
    - all tanks, equipment, electrical cabling, HDPE piping and motors in the CuSX tank farm.
    - a significant portion of the cabling, piping and support gantries in the pipe racks leading to the CuSX mixer-settlers and the downstream USX pulse column.
- No fire damage to the CuSX mixer-settlers or the USX pulse columns.
- Specific major CuSX equipment and/or piping items that were severely damaged or destroyed including:
    - 2 loaded organic tanks/train (pre-scrub and post-scrub) x 2 trains
    - Crud tank and crud processing* tank

  - Scrub solution* tank and spent scrub solution tank
  - Copper raffinate tanks
  - Solvent and electrolyte pipes
  - Electrical cabling
  - Skim filter backwash tank*
  - Electrolyte flotation*
  - 3 electrolyte filters*.

    *damaged after the loaded solvent tanks caught fire
- The HDPE liner of the 1 ML waste dump pond within the CuSX tank farm area was also burnt out.
- The flooding of the tank farm area with fire water led to fire extending well beyond just the first set of fire affected CuSX tanks in the tank farm and to include the more remote copper electrolyte tanks and the copper raffinate tanks, still within the tank farm.
- The flooded/ fire affected area of the CuSX tank farm was approx. 100m x 60m.

**Investigation of the Olympic Dam Copper and Uranium SX Plant Fire, 23 December 1999, Geoff Sulley, District Officer, Fire Cause Investigator, South Australian Metropolitan Fire Service[3]**

This reference by the South Australian Metropolitan Fire Service provides helpful layout and elevation drawings for the Olympic Dam CuSX plant at the time of the first fire at 19:26 hours on 23 December 1999. Points of interest are:

- The fall in elevation in the HDPE loaded organic pipeline from the exit from the E1 CuSX settler to the top of the HDPE lined loaded organic holding tank in the tank farm would appear to have been of the order of 6 metres.
- The fall in elevation in the same pipeline to the bottom of the same organic holding tank would appear to have been of the order of 10 metres.
- The same fall in elevations are understood to have applied in the 2001 fire.
- The drop in elevation from the exit of the CuSX settler to a half-filled loaded organic tank would appear to have been of the order of 8 metres.
- The major drop in elevation would have led to a partly empty drain line, significant organic turbulence, air movement in the line, high organic velocities and consequently significant static generation, all of which were most undesirable.

As mentioned earlier, the combination of factors such as air vents at the start and end of the loaded organic line, the static earthing rings protruding into the organic flow at frequent intervals along the line, the collection of crud at the earthing rings and the rapid drop in elevation near the end of the line would have further contributed to the high risk of fire in the loaded organic drain line and the ultimate fire(s) that occurred in the CuSX plant at Olympic Dam.

## 4. PROCESS DESIGN RECOMMENDATIONS

Subject to the results of an audit of existing CuSX facilities or of proposed new CuSX facilities by appropriately qualified personnel, the following process design recommendations are considered to be the minimum necessary to reduce fire risks in future CuSX operations:

- Existing plants:
  - Ensure organic drain lines to the loaded organic tanks are kept full of organic to minimize any air or organic mist that could support combustion
  - Ensure bottom entry of organic to the organic holding tanks

  - Ensure organic velocity is below 1 m/sec and minimize turbulence in the organic piping
  - Change organic phase drain lines and interconnecting organic mixer-settler piping from HDPE to a suitable grade of stainless steel or FRP with conductive carbon and antimony oxide for fire resistance
  - Establish an organic scuttling system for rapid dumping of organic from mixer-settlers to a fire-safe area
  - Adopt safety protection equipment, clothing and safe practices to minimize static.
  - Adopt restricted personnel access practices for the SX area.
  - Avoid air breather pipes on organic drain lines.
  - Identify limitations of existing foam monitors and injection points under effects of strong cross winds.
  - Conduct a Hazop study including assessment of impact of multiple simultaneous failure events and other loss prevention measures.
  - Undertake modeling to assess the extent of the fire risk.
  - Install water curtains and/or firewalls, where appropriate.
- New plants:
  - Use loaded organic tanks that are close coupled to the corresponding mixer-settlers and at similar elevations to ensure drain lines are kept full of organic
  - Ensure bottom entry of organic to the organic holding tank
  - Ensure organic velocity is below 1 m/sec and minimize turbulence during flow in organic piping
  - Use appropriate grade stainless steel or FRP with conductive carbon, and preferably also antimony trioxide, for organic piping and for organic tanks and vessels
  - Design an organic scuttling system for rapid dumping of organic from mixer-settlers to a fire-safe area
  - Adopt safety protection equipment, clothing and safe practices to minimize static.
  - Avoid use of air breather pipes on organic drain lines
  - Select a plant layout to help minimize the risk of fire spreading significantly beyond its starting point, including consideration of potential wind direction during a fire, using fire flux modeling as a basis.
  - Conduct several Hazop studies at different stages of design including an assessment of the potential impact of multiple simultaneous failure events and the adoption of loss prevention measures that have been proven from experience in the oil, gas and petrochemical industries
  - Install water curtains and/or firewalls, where appropriate.
  - Adopt safety protection equipment, clothing and safe practices to minimize static.
  - Adopt restricted personnel access practices for the SX area.

Excluded from the above list are non-process design issues to ensure conformance with factors such as relevant national static and other fire safety standards; improved instrumentation and utilization of automatic/ manual control of fire fighting equipment; selection of the most appropriate water and foam storage capacity for the plant and other related issues.

Above all, the successful minimization of static and other fire risks in CuSX plants will require the adoption of new designs and operating practices that are more common in the oil, gas and petrochemical industries than the mining and metallurgical industry and will encourage a major change in attitude to the risks of fires in solvent extraction operations.

## 5. REFERENCES


1. Copper prices help Arizona Mining Industry, William R. Yernberg, Mining Engineering, pg 30, February 2005.
2. Industry Newswatch, Mining Engineering, pg 12, February 2005.
3. Investigation of the Olympic Dam Copper and Uranium SX Plant Fire, 23 December 1999, Geoff Sulley, District Officer, Fire Cause Investigator, South Australian Metropolitan Fire Service (Fire No 1, approx 1926 hours, 23 December 1999).
4. Investigation into a fire which occurred at Copper and Uranium Plant SX 21st October 2001, Olympic Dam Copper/Uranium Mine, Roxby Downs, South Australia, Brendan Walker, District Officer, Fire cause investigation Section, South Australian Metropolitan Fire Service (Fire No 2, approx 1210 hours, 21 October 2001).
5. News Release, Phelps Dodge Corporation, Phoenix, October 20, 2003 (Re fire at one of Morenci's four SX plants Oct 16, 2003).
6. Latest News, Fire reported at Phelps Dodge Morenci Facility, The Business Journal, Phoenix, October 16, 2003 (Re fire at Metcalf SX plant Oct 16, 2003, at about 7.45 am).
7. Personal communication.
8. WMC CUD Copper Solvent Extraction Fire, 23-24 December 1999, Investigation Report, Department for Administrative Services, Workplace Services, MA Wilson, Inspector of Mines (Report obtained under Freedom Of Information).
9. Investigation of Copper-Uranium Solvent Extraction Plant Fire at Olympic Dam-21/10/2001, MA Wilson, Inspector Of Mines, July 2002 (Report obtained under Freedom of Information).
10. Designing solvent extraction plants to cut the risk of fires, Gordon Collins, John H Cooper and Martin R Brady, Nonferrous Metallurgical Div., Davy International Minerals and Metals Ltd, E/MJ December 1978.
11. Fire Protection For Solvent Extraction Plants, What We Can Learn From Olympic Dam, Frank Rizutto, Plumbing Engineer, July 2002.
12. Electrostatic Hazards In Solvent Extraction Plants, Peter Haig and Jodie Maxwell, Shell Chemicals and Theo Koenen, Shell Engineering Ltd, Alta Cu 2003, Perth, Australia.
13. What sparks danger in solvent extraction, Graham Hearn, Wolfson Electrostatics, Mining Magazine, pg 32, March 2005.
14. Solvent Extraction Mixer-Settlers and Contactors: Developments and Trends, Mal Jansen and Alan Taylor, International Project Development Services, Alta Copper 1977 Hydrometallurgical Forum, 20-21 October, 1977, Brisbane, Australia.