STROMLO WATER TREATMENT PLANT
UV LAMP BREAKAGE INCIDENT

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ABSTRACT

On 4th July, 2014, an abnormal situation at the Stromlo Water Treatment Plant (WTP) resulted in a very high flow of water through one ultraviolet (UV) treatment train and the subsequent breakage of two UV lamps. Each ultraviolet lamp contains 2.2 g of mercury, which was released into the drinking water.

The UV disinfection system is immediately upstream of the final water storage tank before drinking water is distributed to Canberra and Queanbeyan. Owing to the very small quantity of mercury involved, the risk of customers receiving mercury contaminated drinking water was very, very low. However, the incident was unexpected and unprecedented and the organisation did not have a response procedure. This paper discusses how the incident was managed and investigated and the prevention measures that were subsequently adopted.

KEY WORDS

Ultraviolet Disinfection, UV Disinfection, Ultraviolet Lamp, UV Lamp, UV Lamp Break.

1.0 INTRODUCTION

The Stromlo WTP treats surface water from the Cotter River Catchment, producing up to 250 ML/d of drinking water for supply to Canberra and surrounding regions. The plant comprises flocculation/coagulation, conventional multimedia filtration, fluoridation, and disinfection with both UV treatment and chlorination. It is manned 24 hours per day by a single Water Operator working 12 hour rotational shifts. Located on the outskirts of Canberra, the plant is capable of meeting total customer demand for most of the year.

ACTEW Water has a second WTP at Googong in NSW, which treats surface water from Googong Dam on the Queanbeyan River Catchment. The Googong WTP has a capacity of 270 ML/d, so is also capable of meeting total demand for most of the year. Except for a planned run for one month each year in order to run equipment at Googong WTP and undertake maintenance at Stromlo WTP, the Googong WTP remains offline in a state of readiness, to be brought online quickly if required. This may occur if customer demand exceeds the capacity of the Stromlo WTP during the hot Summer months; or if the capacity of the Stromlo plant is reduced due to planned or unplanned maintenance, water supply restrictions, or a contamination event.

The degree of 'readiness' of the Googong plant to produce water is maintained throughout the year at between 12 and 24 hours, with a shorter online time required during the Summer months when demand is higher and there is greater likelihood that it will be needed.

ACTEW Water is also responsible for water distribution in Canberra and has 47 reservoirs throughout the city. The reticulation network can be fed from either or both treatment plants and is typically operated between 450 - 650 ML, enough to meet demand for at least 24 hours in the event of a major failure at the online WTP.

On 4th July, 2014, a control logic fault caused the flow control valve on the main feeding the Stromlo WTP to open unexpectedly very quickly. The excessive rate of flow increase resulted in an exceedance of the maximum flow rating through a single UV disinfection train. This caused two mercury-containing UV lamps to break, resulting in a release of mercury into the process water stream.

Drinking water quality in the ACT is governed under the *Public Health Act, 1997*, which is administered by ACT Health. ACTEW Water is required to manage drinking water quality to the specifications in The Australian Drinking Water Guidelines (ADWG). Maintaining a continuous supply of safe drinking water was the highest priority during the management of this incident.

2.0 DISCUSSION

2.1 UV Disinfection System

Stromlo WTP has a Calgon Sentinel UV Disinfection system. It is the second last water treatment step after filtration and before chlorination. It consists of 3 parallel treatment trains which can each treat up to 150 ML/d. Each train has three banks of two UV lamps which are orientated perpendicular to the direction of water flow.
Figure Figure 1 shows a typical single train with lamps visible through the left side.
Figure 2 shows a single lamp bank at Stromlo WTP with the cover removed. Two lamps are installed and the position for a third has been blanked off.

Figure 1: ***Calgon UV Treatment Unit with 3 Lamp Banks***

Figure 2: ***UV Lamp Bank with Cover Removed***

Each 20 kW UV lamp contains 2.2 g of mercury within the lamp tube. The lamp tube itself is housed inside a quartz sleeve, protecting the lamp from the water flow. When electrical current is applied to the tube, the mercury is vaporised and it's excitation generates UV light. The mercury vapour lamps are manufactured by Calgon Carbon and supplied by local vendor Liquitek.

The quartz sleeves have been tested by the manufacturer to a maximum flow through one train of 159 ML/d. Allowing a 5% safety margin, Calgon recommend that the sleeves should not be subject to flows exceeding 151 ML/d and this is the maximum flow at which Calgon provide a guarantee. Calgon state that the sleeves are likely to withstand higher flows, but cannot say at what flow the quartz sleeve will break.

2.2 Incident Description

At 5:47 am on Friday 4th July, 2014, the flow control valve on the 675 mm diameter main feeding Stromlo WTP unexpectedly opened from 14% to 100% in 9 minutes, increasing the raw water flow to the plant from 99 ML/d to more than 180 ML/d at more than double the usual maximum rate of flow increase.

As a consequence of the rapid increase in raw water flow, the flow through UV Train 3 reached 239 ML/d, that is, 58% greater than the maximum flow rating of the UV disinfection unit. Under normal circumstances of controlled increases in flow, additional UV trains automatically come online, but the rate of flow increase was faster than the start-up sequence for an additional train.

At 5:59 am, the control system automatically shut down Train 3 and brought the other two UV trains online to continue processing inflowing water. This took about ten minutes.

A number of alarms annunciated:

1. Train 3 Actual flow above validated range,
2. Train 3 UV Transmittance Low,
3. Train 3 Lamp Faults (multiple lamps).

The alarms were acknowledged at the time and the plant remained online, but the Operator raised the possibility of lamp breakage with Process Engineers. They concluded that breakage of a quartz sleeve and UV lamp was extremely unlikely and had never before occurred in the plant's 7 year operating history.

Electricians were sent to inspect the lamps in the offline UV Train 3 at 10:00 am. They removed the covers and found the broken lamps.

Figure 3 shows the view through the sleeve mounting with the broken sleeve end removed. The other end of the broken sleeve is visible through the pipe. The unbroken lower sleeve and lamp on the same bank are also visible. There were no signs of any pieces of the actual mercury lamp, which had been carried away in the drinking water flow.

Figure 3: ***View through Lamp Sleeve Mounting***

2.3 Incident Response

When the broken lamps were found, the immediate response to confirm containment was to shut down the plant and isolate the final storage tank at the WTP, stopping the flow of water to the distribution network. The plant had been producing 100 ML/d and there was 540 ML in the network, so there was a maximum of 24 hours before supply would become critical.

ACT Health was notified of the incident within three hours. They advised that the tank immediately downstream of the UV treatment facility (the Post UV Tank) should be swabbed and tested for mercury and that the Stromlo WTP should only be brought back online after obtaining a negative test result.

The Post UV Tank could have been emptied, cleaned and swabbed that day, but mercury test results would not have been available for three days due to it being a Friday. It was therefore necessary to start up the Googong WTP in order to maintain continuity of water supply.

Resources were redirected from Stromlo WTP to Googong WTP at 1:00 pm that day. The Googong WTP was producing water by midnight that night. Googong WTP remained online for two months because the business took the opportunity to undertake some planned maintenance.

Prior to bringing the Stromlo WTP back online, the Post UV Tank was drained, cleaned and swabbed inside. The swabs were tested for mercury.

2.4 Technical Incident Investigation

A team of six people undertook a formal Root Cause Analysis (RCA) investigation over two days to investigate the technical cause(s) of the UV lamp breakages. Training in the RCA technique had very recently been rolled out to a number of staff, so this was an opportunity to test the value of the tool.

Starting at the ‘fault’ of UV lamp breakage, the team worked backwards to investigate all possible mechanisms which could have led to broken UV lamps. Assessing each branch in detail identified the root cause as a fault in the PLC control logic for the control valve on the raw water main to the treatment plant.

The logic fault caused the valve to open very fast, resulting in a very high rate of flow increase into the plant, and subsequently, a very high rate of flow through the single online UV train. This caused two quartz sleeves and UV lamps to break from the force of the fast flowing water.

The RCA tool also enabled the team to identify other mechanisms which could also result in lamp breakage. This was valuable because these are additional process safety risks which also need to be controlled.

2.5 Risk to Drinking Water Quality

Health guideline values for contaminants in drinking water are set by The National Health and Medical Research Council and specified in the ADWG. The Health Guideline value for mercury is 0.001 mg/L (ADWG 6 2011, Version 2.0 Updated December 2013, Table 8.4, p. 108).

The quantity of mercury released into the water from the two broken lamps was 4.4 g. There was 24 ML in the final reservoir at the WTP at the time of the incident and 540 ML in the reticulation network. The theoretical mercury concentration if 4.4 g were evenly distributed in the final reservoir would be 0.0002 mg/L, that is, one fifth of the health guideline value. This doesn't consider the dilution effect of the reticulation network. Therefore, the risk to customers of receiving mercury contaminated drinking water was negligible. This is supported by the following quotation:

> *"Larger systems and systems with clearwells need only be concerned minimally with on-line lamp breaks. This is because the amount of water flowing through the system and/or the clearwell volume will dilute the mercury concentration to concentrations that are far below the MCL for mercury, as set by the EPA. Mass balance analysis suggests even if all of the lamps in a typical MP UV reactor were to break in most typical drinking water systems, the water will be safely diluted by the time it exits the clearwell."* Borchers et. al.

However, the ADWG specifically suggests that where UV disinfection is utilised:

> *"a site-specific mercury spill response plan should be established to minimise mercury release in the rare event of a lamp breakage"* (ADWG 6 2011, Version 2.0 Updated December 2013, Information Sheet 1.7, p. 209).

A formal debrief with the regulator was undertaken. Feedback from ACT Health was that the lack of identification of the hazard in the Drinking Water Quality Management Plan, and in particular, the lack of a response plan for a broken UV lamp, resulted in reactive decision making within both agencies. Responding to an unknown risk at ACTEW Water resulted in a significant interruption to the business.

2.6 Preventative Measures

A number of preventative measures were implemented to reduce the probability of recurrence. Engineering measures involved control logic changes, including:

1. Repair of the control logic error (including other identified instances).

2. Configuration of an upper limit on the raw water set point which is a function the number of UV trains available.
3. Configuration of an alarm on the rate of change of flow feeding the plant.

The incident demonstrated that the immediate actions taken by the Water Operator are crucial to containment of the hazard. A procedure was developed to provide guidance to Water Operators in responding to suspected or confirmed UV lamp breakages. The Water Operator response should be to initiate a full plant shut down, isolate the UV train and immediately escalate to the on-call Water Distribution and Water Treatment Engineers. The Engineers will then assess the risk to water supply and quality and coordinate a response.

The root cause analysis also identified a number of possible control measures of a longer term/design nature, such as a physical flow restriction on individual UV Trains. It was determined that a formalised Failure Mode Effect and Criticality Analysis (FMECA) workshop should be undertaken on the Stromlo WTP in order to systematically assess the entire plant for process risks. This is planned for 2015.

The incident details, investigation and outcomes were thoroughly communicated to all personnel. Communication to Water Operators was via email and in person. Emphasis was placed on the need to shut down the plant in an uncontrolled/abnormal situation. A presentation was made to the Asset Management Group.

3.0 CONCLUSION

This incident alerted ACTEW Water to the risk of UV lamp breakage, which had not previously been identified by the business in the Drinking Water Quality Management Plan. In this case, the risk of sending mercury contaminated water to customers was quantified and found to be negligible.

Operators play a critical role during incident response. ACTEW Water Operators are now aware that UV lamp breakage is possible and they know how they must respond if it does occur. The response plan is formally documented in a procedure.

The incident investigation demonstrated the value of the root cause analysis technique, which has been further embedded into the business as a standard incident investigation tool. It also highlighted the need to undertake further detailed and systematic process safety risk analysis to ensure that all process safety risks have been identified and controlled. This will be undertaken using Failure Mode Effect and Criticality Analysis.

4.0 REFERENCES

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