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TITLE: -
THE EXPANSION OF "CONCEPTUAL HAZOP" TO COVER DIVE SITES

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ABSTRACT

There are approximately 10,000 professional dives carried out each year in BC. There are on average three fatalities to professional divers every two years in BC. Many of these dives are due to a lack of an appropriate Hazard Identification at the dive sites, rather than to a lack of skill by the divers themselves.
After a particularly tragic and unnecessary fatality at a Pulp Mill in BC, the Workers' Compensation Board invited the author to explore the scope for the use of HAZOP to reduce diving accidents. An expanded version of the so-called "Conceptual" or "Creative Checklist" "HAZOP" was developed, and with the approval of the Workers' Compensation Board was submitted to a client for experimental use.
The local Utility Company BC Hydro, makes extensive use of divers at its dams, the Burrard Thermal Power Station and for underwater cables. With the encouragement of the Workers' Compensation Board, BC Hydro agreed to have a trial HAZOP at two of its sites. These trials were very successful. A number of hazards were identified and appropriate steps taken. Not only were the dives carried out without unforeseen incidents but also, in the view of the clients' the work was speeded up and money was saved.
The paper will briefly describe some of the theoretical work, together with examples of the methodology in practice. BC Hydro is considering revising the diving safety standard to include HAZOP

INTRODUCTION

There are approximately 10,000 professional dives in BC each year. This number may increase significantly if offshore resources are to be developed. There are approximately three diving fatalities in BC every two years. Many of these fatalities could have been avoided if adequate attention had been paid to the identification of the hazards which exist at the sites where diving will take place, rather than the hazards caused by the work of the divers, themselves.
After a particularly tragic fatality at a pulp mill in BC, the Workers' Compensation Board of BC (WCB) formed a Task Group to try to find ways of reducing fatal accidents to divers. During the working period of this Task Group, a member of BC Hydro suggested to the WCB, that an awareness of HAZOP could be beneficial. As a result of a presentation on HAZOP to the WCB, the WCB invited the author to see if HAZOP could be modified to improve diver safety. The results of the proposed modifications were encouraging and the WCB suggested that a client should be found and some trial HAZOP Studies carried out, to validate the methodology. With the support of the WCB, BC Hydro agreed to have some trial HAZOP Studies carried out at some of its dive sites. The actual trials are discussed later, but it is first necessary to discuss in more detail, the type of HAZOP it was proposed to use and the modifications to the chosen type.

“CONCEPTUAL HAZOP”

Once the conventional HAZOP (Guide Words on the Elements of the Design Intention) was established, it was found to be necessary to supplement this very powerful approach with another version, which focused on the “Work Site” rather than the “Work Content”. This supplementary approach could be carried out at a very early stage in a project and provided a means of identifying adverse interactions between a proposed plant and its surroundings. The method uses a list of about forty “Prompts” which cover energy, “interactions” e.g. materials on people – “toxicity” and environmental issues. The methodology has had considerable success but is probably still under-utilized by the Process Industries. Details of the method are given in refs. 1, 2 and 3. As shown in ref. 3 this HAZOP not only saved $30 million in costs and a years delay, but was also identified the hazards which the site posed for construction workers and assisted the project to achieve an outstanding record for construction safety

EXPANSIONS FOR DIVING SAFETY

The expansions take two forms namely: -

EXPANSION OF THE PROCEDURE

EXPANSION OF THE PROMPT LIST

EXPANSION OF THE PROCEDURE

The methodology uses the same procedure as a conventional HAZOP, namely: -

DEFINITION
PREPARATION
EXAMINATION
FOLLOW UP

However each of these steps is more elaborate for diving than for surface hazards.

DEFINITION

All professional dives have surface support personnel in addition to the divers. Therefore the geographical scope of the study must include both surface and under-water areas for hazard identification. The number of potential hazards is nearly doubled. A team carries out the HAZOP as usual. Ideally, the team should include someone with professional diving experience as well as a Study Leader trained in this type of HAZOP.

PREPARATION

Not only is the scope larger but also the collection of data for under-water hazards is more time-consuming. Surface hazards can often be seen on a broad scale by inspection of the site. Underwater hazards are not always as immediately visible and historical or indirect methods such as sonar may have to be employed. The sources of information are more extensive. For example, charts as well as maps, current and tide tables as well as meteorological information. The preparation should include the planning for the positioning of the surface support as well as the positioning of the divers at the work site.

EXAMINATION

Although the number of items considered is nearly doubled compared to the "Conventional" Conceptual HAZOP, to date the Examinations have not taken very long; one to two days. It appears essential that the person who will brief the divers prior to the actual dives should be a member of the team

FOLLOW UP

The Examination produces "Work Assignments" as in a conventional HAZOP. However these work assignments can involve more complex administration than in a conventional HAZOP. Some work assignments are given to the client of the divers and simply involve either making the site itself safer or by installation of extra "safeguards" against hazards which can be encountered by the divers. Others involve negotiations with the diving organization, prior to the dive. A further stage of the follow up involves the discussions of the dive itself in what is called the "tail-board" meetings, which take place between the clients' personnel and the divers at the dive site, just before first the dive.

EXPANSION OF THE PROMPT LIST

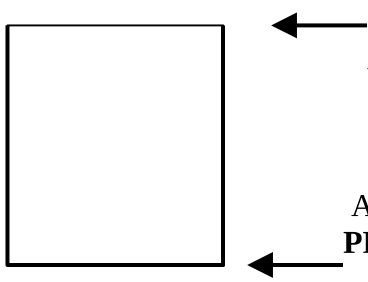
As the hazards can affect the surface support team, all the conventional “surface” hazard items remain relevant. Some items have a changed emphasis. For example, the visual impairments caused by glare or mist, tend to be treated as “nuisances” rather than life threatening, although they some times pose serious hazards. However the visual impairment for divers is very frequently life threatening Items such as weather will have to be augmented with the under water phenomena such as tides and currents.

In addition to these fairly straight- foreword additions, there is another factor, which is due to the density of the working medium. This factor which is the cause of many fatalities is added to the “energy” factors and has been given the name of “fluid energy”

FLUID ENERGY

Consider the tank of water, “H” ft high shown in figure 1, below: -

FIGURE 1



AT THE TOP, A DROP OF WATER WILL HAVE THE **POTENTIAL** ENERGY OF “H”

AT THE BASE, A DROP OF WATER WILL HAVE **PRESSURE** ENERGY, WHICH IS A FUNCTION OF “H”

If a drop of water spills from the top and falls in air to the level of the base of the tank it will exchange its potential energy to **KINETIC** energy.

If a drop of water escapes from the base and is released into air, it will exchange its pressure energy to the same **KINETIC** energy and attain the same speed as if it was released from the top of the tank and allowed to fall in air to the base

A diver operating at the same density as water will be subjected to the same balances of energy. Thus if a diver is operating at the base of the tank and there is a sudden release of pressure, the diver will be propelled at the same speed as if the diver had fallen in air from the top of the tank. These three forms of “fluid” energy are interchangeable. Thus if the diver was stopped by an obstruction and sealed off the opening, the diver will then be subjected to a differential pressure energy which is the same as the original function of “H”

This factor of “fluid energy” has to be included in the energy list of prompts

Fluid energy can be used for the design of guards placed at openings to prevent the ejection or engulfing of divers, without causing them impact damage.

Fluid energy can also be used to calculate the safe “limits of approach” for a diver to approach an unguarded opening, from the knowledge of “H”, together with the diameter of the opening. This concept is in principle the same as the use of “limits of approach” by the electrical industry, which is based on voltage.

BC HYDRO – STAVE LAKE EXAMPLE

Stave Lake is a medium-sized BC Hydro generating station about 40 kms east of Vancouver. It consists of a dam running approximately east/west with two generating stations south of the dam. Stave Lake itself is north of the dam and about 40 kms long. The west generating station was out of use and was being converted into a "presentation centre" to explain the workings of a station to the general public. The east generating station was much larger and in current use.

The dam was being up-graded by adding fill to the south side. The purpose of the fill was to enable a two-lane road to be built across the dam and thus enable a small single-lane bridge to be removed. In addition the added fill would strengthen the dam against earthquakes

The purpose of the dive was as follows: -

During the construction of the dam in the early 1900's, a 12-inch pipe was taken through the dam near the bottom. The pipe was fitted with a "T" piece at the upstream end and the pipe extended about 18 feet into Stave Lake. The pipe was fitted with a valve on the down-stream side, which was normally closed. This valve would be covered with fill during the upgrading. It was therefore decided to take the pipe out of service, by filling it with concrete. In order to do this the "T" piece would be removed from the flanged end of the pipe. A blank would subsequently be bolted to the flange. The blank would be fitted with a vent, which would rise above the water level. This would enable the water to be drained out by opening the valve. The water would then be replaced by pumping concrete through the valve.

At least two dives would be required. The first dive would locate the "T" piece, if possible, remove it and measure the flange for the vented blank to be fabricated. The second dive would be to fit the blank.

A sub-contractor to the prime contractor who was handling the dam up-grade would carry out the dives.

A sketch of the dam is shown in figure 1 on the next page.

This diving operation was chosen as the first trial of the modified conceptual HAZOP procedure.

DEFINITION

This step was straight-foreword. The scope of the study included the dam, the area for surface support and the relevant area of Stave Lake. There were a number of constraints. For example the power plant would remain in operation. The lake could not be drained. The road and bridge would remain open.

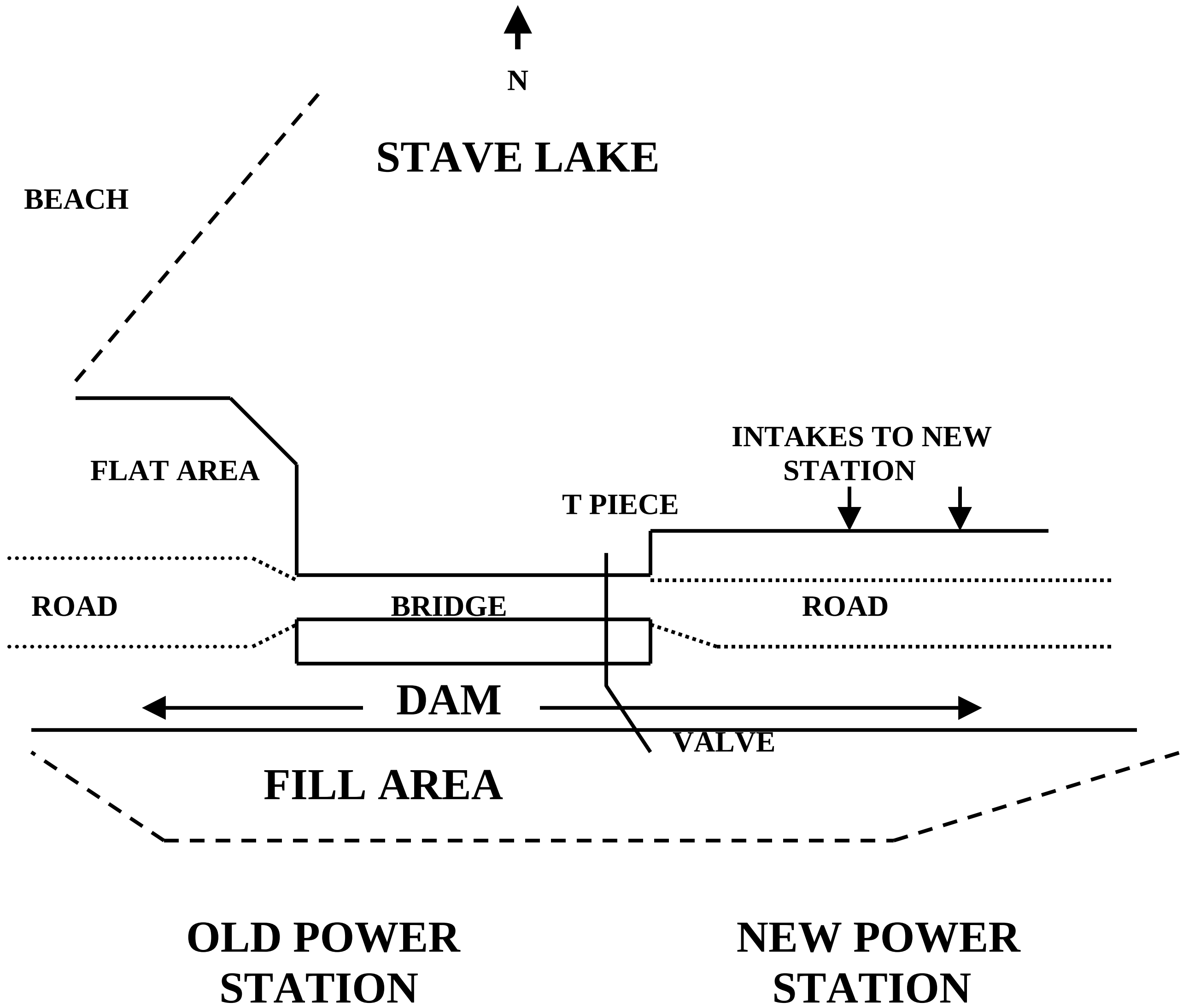
PREPARATION

This had two aspects, namely data collection and planning the dive

Data collection

This was extensive. Topological maps, aerial and surface photographs were collected, some dating back to the construction of the dam. Drawings old and new. Meteorological Data, Sonar information and information on the under-water floor of the dam. The data collection was guided not only by the Definition, but also by the Prompt List.

FIG.1 PLAN VIEW OF STAGE LAKE DAM



Planning the dives

The information collected showed that the dive would have to take place vertically down from the approximate location of the “T” piece. This was because the floor of the dam was strewn with rocks. The “T” piece appeared to be just clear of some “trash racks” which were in an unknown state of repair and the “T” piece was, from sonar measurements, likely to be at the edge of the “debris field” created by the trash racks. Surface support could not be provided from the bridge or the dam. It would have to be provided from a boat. It would be very difficult to launch the boat from the beach. The safest solution was to have the boat lowered vertically by crane into Stave Lake from the flat area next to the bridge and “walked” by the crane to the beach. It could then be boarded and motored to the dive site.

EXAMINATION

This was carried out by a small team in two half-days using the prompt sheet for the various activities such as “Position surface support” “Execute inspection dive” etc. A total of 25 issues were raised and recorded on a work sheet with work assignments as usual. The work sheet was slightly different to the usual Conceptual HAZOP work sheet, as it contained provision for recording the responses of the divers to the briefing, which they would receive later. There were many more potential issues, which the data collection had shown to not be applicable to the Stave Lake dives. For example, there was no potential for avalanches or mudslides and the nearest rock fall areas were well clear of the dive site. On the other hand there was a storm water run off close to the dam which could cause visibility problems under adverse weather conditions. The main problems were the possibility of the diver being flung into the “T” piece, if there was an escape of water from the pipe and held there by a force of 2 to 3 tons. Rescue would be impossible. There were also problems of entanglement, as the “T” piece was at the edge of a debris field. Positioning of the support boat also had problems. For example it was considered to be too dangerous for anyone to be in the boat when it was lowered into the water. Many of the boat problems were dealt with, provided the boat was equipped according to the Coast Guard regulations for small craft. However, as the boat had a gas-powered engine and the boat contained compressed air cylinders for the diver, it was recommended that a “no smoking” rule should be adopted This was a working construction site and care would have to be taken to ensure that no, un-related construction activities, should interfere with the safety of the divers.

FOLLOW UP

The follow up had several stages

Firstly there were final negotiations with the diving sub-contractor.

On the appointed day, the dive team, together with the head of the diving company arrived on the site. The BC Hydro engineer who had also carried out most of the preparation stage and who had participated in the HAZOP, briefed them for the job. All the HAZOP recommendations were accepted. The lead diver was so impressed with the dangers of water flow into the “T” piece that he insisted on putting his own lock on the valve.

THE FIRST DIVES

The boat positioning and first dive proceeded as expected. The diver found a log jammed against the “T” piece, which had to be towed away before the work could proceed. The “T” piece was removed by cutting the bolts and a wooden template was constructed as the model for the blank. During the dives, a construction crew wanted to bore holes in the dam. As these could penetrate the pipe, the boring was not permitted. Also during the dive, a crane was operating on the top of the dam. This was permitted, provided the crane arm did not pass over the water. There was nearly a further problem. As the dive was taking place almost underneath the bridge, there was a potential problem from traffic Accidents, during the dive. As the traffic over the bridge was very light, controlled by traffic lights to a single one-way operation and the bridge was sufficiently robust to withstand a traffic accident, it was felt that no additional precautions were necessary. However, during the briefing of the divers, the traffic lights failed. As a consequence, vehicles from both directions were entering the bridge at the same time. Fortunately the traffic light fault was rectified. Otherwise it would have been necessary to station flagmen.

At the end of the debriefing after the dives, opinions were sought on the effectiveness of the HAZOP. There was very strong support from the managements of BC Hydro, the construction sub-contractor and the manager of the diving company. The dive team was supportive of the thorough briefing they had received and the fact that there were no surprises. On minor comment from the back-up diver was that he felt there had been a slight “overkill”. The response of the BC Hydro manager was that in diving, there could be no such thing as “overkill”

FINAL DIVE

A week later when the blank had been fabricated, there was the final dive to fit it. This was carried out very quickly (about half an hour) with no incidents

GROUTING

The final stage of the decommissioning consisted of filling the pipe with concrete from the downstream side. Initially, it was proposed to drain out the water once the blank had been fitted, measure the volume of the water and add an equal volume of concrete. However, the pressure calculations carried out for the fluid energy part of the HAZOP, suggested that the pipe may bend upwards and implode because of buoyancy, end pressure and pressure on the outside of the pipe. The procedure was then changed to adding the concrete without first draining the water. This was carried out without incident

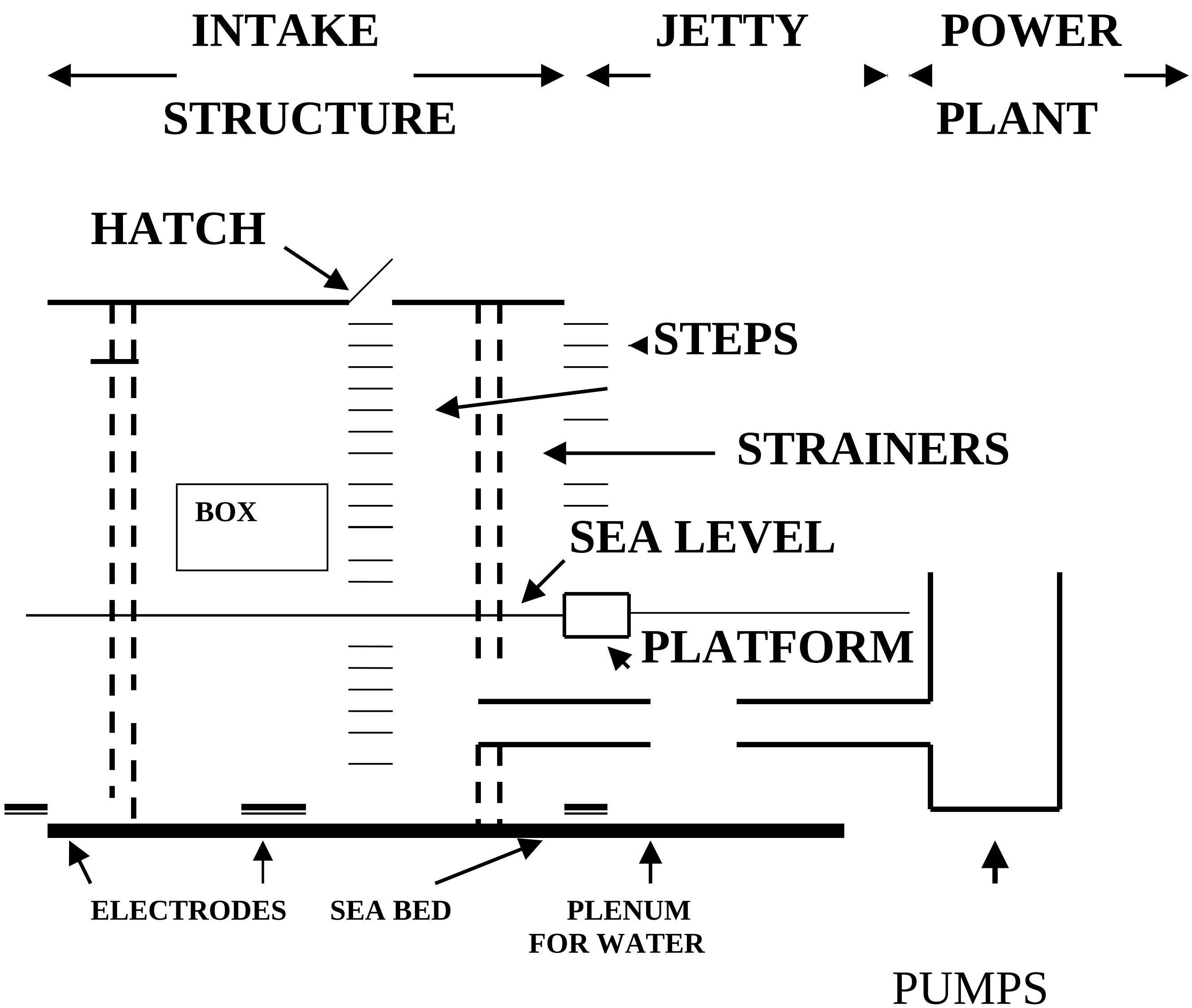
BC HYDRO BURRARD GENERATING STATION

The Burrard Generating Station of BC Hydro generates electric power from steam turbines. Gas-fired boilers provide the steam and after passing through the turbines it is condensed by indirect cooling with seawater. The seawater comes from an intake structure situated in deep water in the Burrard Inlet and adjacent to the Power Plant The structure is connected to the shore-based power station via a jetty. The structure itself is a hexagon in plan. The sides of the hexagon contain continuous, vertically moving screens to filter out debris. Seawater flows from outside through the screens to an inside “box” and then via pipes to the power plant. At the top of the hexagon is a platform, which contains hatches, which give access via vertical ladders to the screens both inside and outside the box. There is also a vertical ladder down to a floating platform on the outside of the structure. The structure is about 24 ft. above the water at low tide.

DIVING WORK

There are electrodes on the seabed both inside and outside the box. These require periodic inspection by divers. In addition, there can be other forms of maintenance work by divers around the structure. Work inside the box can be carried out only when the station is shut down. Work outside the box can be carried out at any time. SCUBA divers can carry out inspection work. Surface supported divers must carry out all other work. A sketch of the unit is shown on the next page

POWER PLANT


INTAKE
STRUCTURE
JETTY
POWER
PLANT
HATCH
STEPS
STRAINERS
BOX
SEA LEVEL
PLATFORM
ELECTRODES
SEA BED
PLENUM
FOR WATER
PUMPS

DIVING HAZOPS

Following the success of the Stave Lake diving HAZOP it was decided to carry out a "Generic" diving HAZOP which would cover all types of dives, with the station in both shut-down and generating modes i.e. a total of six types of dive.

DEFINITION AND PREPARATION

These were carried out as before. The prompt list was again used to guide the data collection. The data not only included engineering drawings but sea charts of the area and local tides and currents tables. It was not necessary to plan these dives. Such dives had been carried out for many years and there were established patterns of diving.

EXAMINATION

The examination was carried out with a team of about four people, and lasted nearly two days for all six types of dive. The prompt sheet was divided into eight vertical columns, one for each type of dive and one for the surface support activities for both SCUBA and surface supported dives. Whenever there was one or more work assignment for any particular hazard/dive combination, the prompt sheet would be marked by a bullet, as usual. However as this was a generic HAZOP, the marked up prompt sheet would not only demonstrate due diligence in the HAZOP Examination, but also act as an index, so that appropriate work assignments could be extracted for any particular type of dive and mode of station operation

A large number of work assignments were generated. Of these the most significant was the lack of fall protection for divers when descending up to 24 ft to sea level. A fall from such a height could injure or kill a diver and rescue or recovery could be difficult. There were a number of steps, which could be taken, which would minimize the risks to divers. Although there were appropriate lockout or tag-out procedures these could be extended. For example, the electrodes could, under normal operation, give a slight shock to a diver. If there were any defects in the electrical supply system more severe shocks could be the result. It therefore seemed sensible to deactivate these electrodes for the period of the dive. The impact on the corrosion of the structure would be negligible. The station used supplies of toxic materials such as ammonia and sulphur dioxide. Arrangements should be made so that there were no deliveries of these materials when a dive was in progress. This would minimize the chances of a toxic spill, which could affect the diver, the surface support staff, and the supply of air to the diver.

There were two potential problems, which were solved by the "fluid energy" concept. One of these was concerned with a diver operating inside the box with the plant shut down. The question concerned the potential impact of a rising tide creating sufficient flow into the intake to the plant, that a diver could be sucked into the intake. The tide tables showed that the maximum rate of tide rise in the port of Vancouver was 2 ft per hour. This was then translated into the appropriate limit of approach and the effect was found to be negligible. The other was the potential impact of the flow through the screens into the box, on a diver working outside the box, when the plant was in generating mode. The screens had been designed so that fish would not be harmed by the equivalent of a fall of 2 to 3 inches and it was felt that this standard would also provide adequate

protection for a diver. The next question was whether a diver could be trapped against a screen by the incoming water, be unable to escape, and be suffocated by the differential pressure. Divers have been killed in such a fashion. Pressure drop calculations suggested that even under the most adverse conditions, a diver would not be suffocated and should be able to escape. However divers should be warned not to venture too close to the screens, as they would feel the impact, and the escape would require some effort.
There were a number of other recommendations, for example the divers should have tide tables. One of the potential hazards was of a surface vessel approaching too closely during a dive. This was possible, as the charts showed that the intake was in the same depth of water as a nearby jetty. If a vessel was relying solely on is depth sounder, it could approach the intake too closely or even collide with it, for example in fog. There were three recommendations: - The divers should have and display the international "divers active" flag, BC Hydro should inform the Port of Vancouver when a dive was proposed and the dive company should consider providing a "loud hailer" for use by the dive supervisor. The current tables suggested that the maximum current in the vicinity of the intake could exceed 1 kt. And therefore SCUBA divers should have a tether. The tether would also act as a communications vehicle should an emergency arise elsewhere on the station, which could call for evacuation of the facility.

THE FIRST DIVE AT BURRARD.

About two months after the HAZOP, the first dive was scheduled. This was a SCUBA inspection of the electrodes, during a complete shutdown. The necessary would assignments were extracted from the generic work sheet and circulated two weeks before the shutdown. By this time, BC Hydro had designed and installed a suitable fall arrest system. The necessary lockouts etc were carried out and the divers briefed. Once again the person carrying out the tailboard briefing had participated in the HAZOP Examination and was able to brief the divers on the hazards and what was expected of them. The dives were carried out without incident over a two-day period. The divers readily used the fall arrest system, which clipped on to their rescue harness.

DIVERS COMMENTS

The divers had mixed feelings about the HAZOP. They were glad to be briefed on all the hazards and the steps taken to minimize them. They were also pleased that the necessary permits were available for them to start work. They felt that there was an element of "over-kill". Initially they felt it was not necessary for them to have tide tables, although on the second day their work pattern made the tide tables very useful.

STATION MANAGEMENT

The management of the Power Station requested a presentation on the HAZOP and were satisfied with the results, particularly that this was a "generic" HAZOP and would be valid for all anticipated dives for the next 5 years, provided that these were the same as the dives already studied.

BENEFITS OF DIVING HAZOPS

The first set belongs to BC Hydro after the Stave Lake HAZOP. Which were as follows

- Recognize factors we had overlooked and information we needed not only from a safety point of view but also from an operational perspective
- Site tailboard meeting more effective
- Demonstrated due diligence
- Proved as useful exercise in the job, in the job, saved time/$ by identifying best choices in what to do next to accomplish objective.
- Versatile method for any diving operation; easy to do when trained properly
- GREATER ASSURANCE OF SAFETY.

The above nearly says it all; only a few more comments are necessary

- All management, BC Hydro, the management of the Stave Lake prime contractor and the management of the Stave Lake diving sub-contractor, all welcomed the methodology.
- It appears possible to apply the method not only to one-off dives but also to use a "generic" version for frequently used sets of dives.
- Apart from a slight feeling of "overkill", the approach was welcomed by the divers themselves

CONCLUSIONS

Diving HAZOP is at the same stage reached by Guide Word HAZOP in the 1960's - a few examples but no track record.

- It needs more extensive validation. This may be best carried out within the Process Industries which are already familiar with HAZOP and its benefits
- The experience with diving suggests that "Conceptual" HAZOP has an even greater applicability to a wide variety of safety problems, than previously realized.

ACKNOWLEDGEMENTS

Thanks are due to the Workers' Compensation Board of BC and to BC Hydro for their initiative in supporting the concept of HAZOP as applied to the safety of Dive Sites. Thanks are also due to the organizers of the Conference for the opportunity to present this paper

REFERENCES

1 Process Safety Management (control of acute hazards) Chemical Manufacturers Association, Washington DC.

2 A Manual of Hazard and Operability Studies. R Ellis Knowlton Aker Kvaerner Chemetics, Vancouver.

3 Conceptual HAZOP as a Strategic Tool. Suncor SO2 Reduction Plant – Case Study. R. Ellis Knowlton. PPR '96 MIACC Conference, Edmonton, Alberta, November 1996.

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