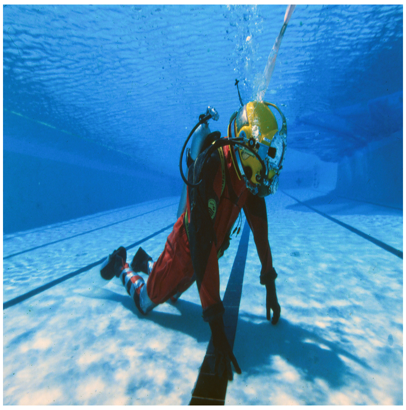


The development of Nuclear Diving in South Africa

Description

ESKOM DIVING SUPERVISOR

MAY 1988

Postscript â€" June 2022

When this article was written in 1988, it was 8 years since the first Koeberg reactor was commissioned. At that time there was a lot of opposition to nuclear power generation worldwide. Some of the objections were, I believe, valid at the time but many were ill informed. Allow me to address a few.

1. *â€œSouth Africa had an abundant supply of high grade coal to use for power generation and did not need nuclearâ€•.* While Climate Change was seldom discussed back then, it is a hot topic now. Many countries that cut back on nuclear are reconsidering as the industry contributes very little to greenhouse gasses. Thanks mainly to greenhouse emissions and the ongoing uncertainty over Russian oil and gas supply, the UK and France, amongst others, are looking into nuclear once more.

2. *â€œIt is very expensive to build and runâ€•*. That was a valid argument in 1980 with the cost of Koeberg spiralling out of control from R850 million to R3.5 Billion but now, with the rapidly increasing oil and gas (by gas I do not mean petrol, that is a liquid) price and the huge carbon footprint of coal, nuclear looks more appealing. Regrettably there is insufficient water in South Africa for large scale hydro and wind and solar have got a long way to go before it can power a country like South Africa with power hungry industries and mining.

3. *â€œWhat about the radioactive waste that lasts thousands of years?â€•* Fortunately the industry has made significant progress with fast breeder reactors that will operate far more efficiently, reducing operating costs and requiring less waste management.

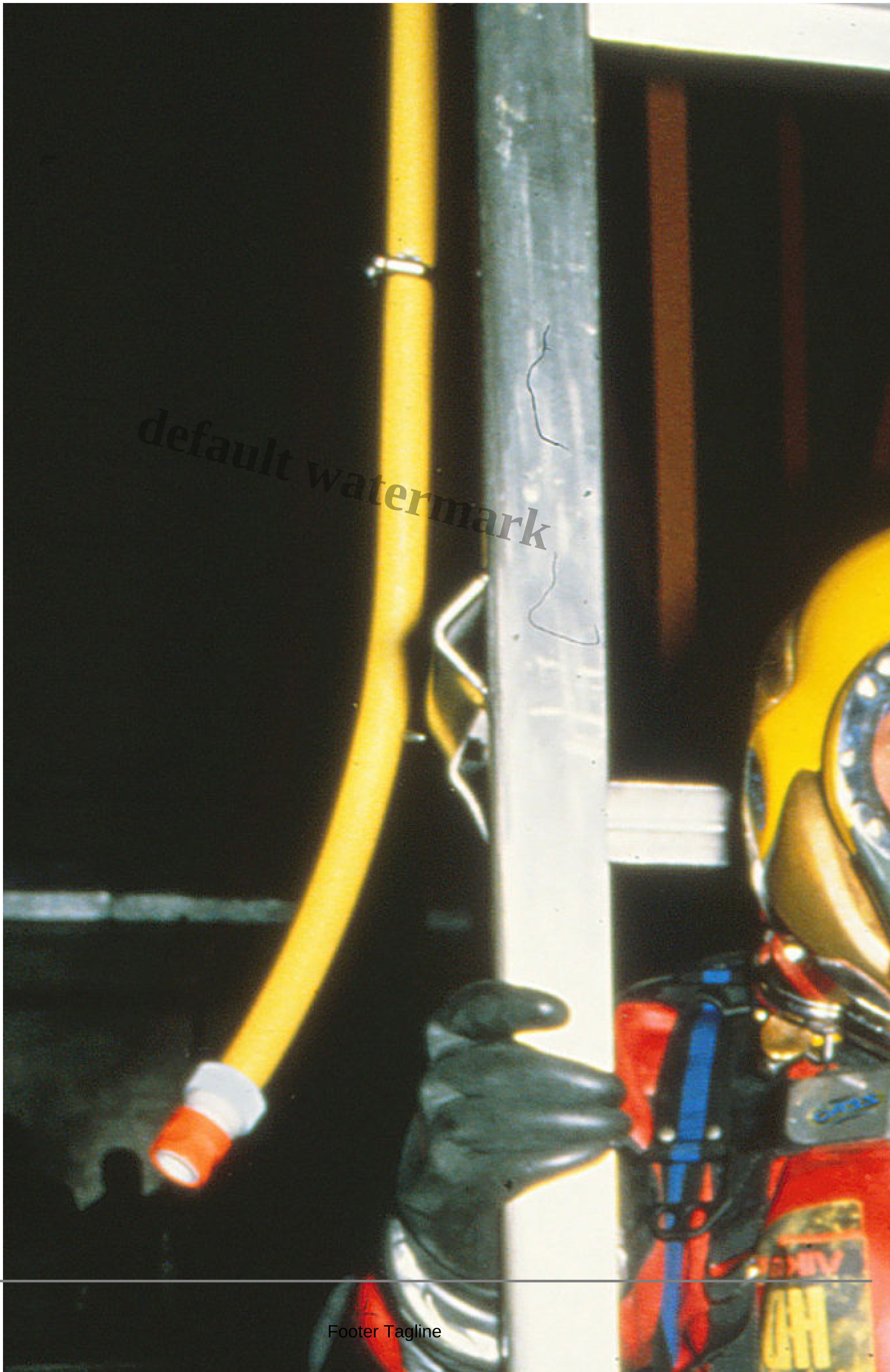
4. *â€œNuclear power stations are dangerousâ€•.* Yes, potentially they are. The worst accident by far involved a Russian reactor but the design and safety standards were extremely poor compared to those in the West and not to be compared with the French designed and built Koeberg plant. Just

take a look at the Russian tanks performing so poorly in the Ukraine at present to get an idea of the poor standard of Russian technology. The level of safety and care that I experienced by Koebergâ€™s Health Physics personnel during this diving operation was, without doubt, world class.

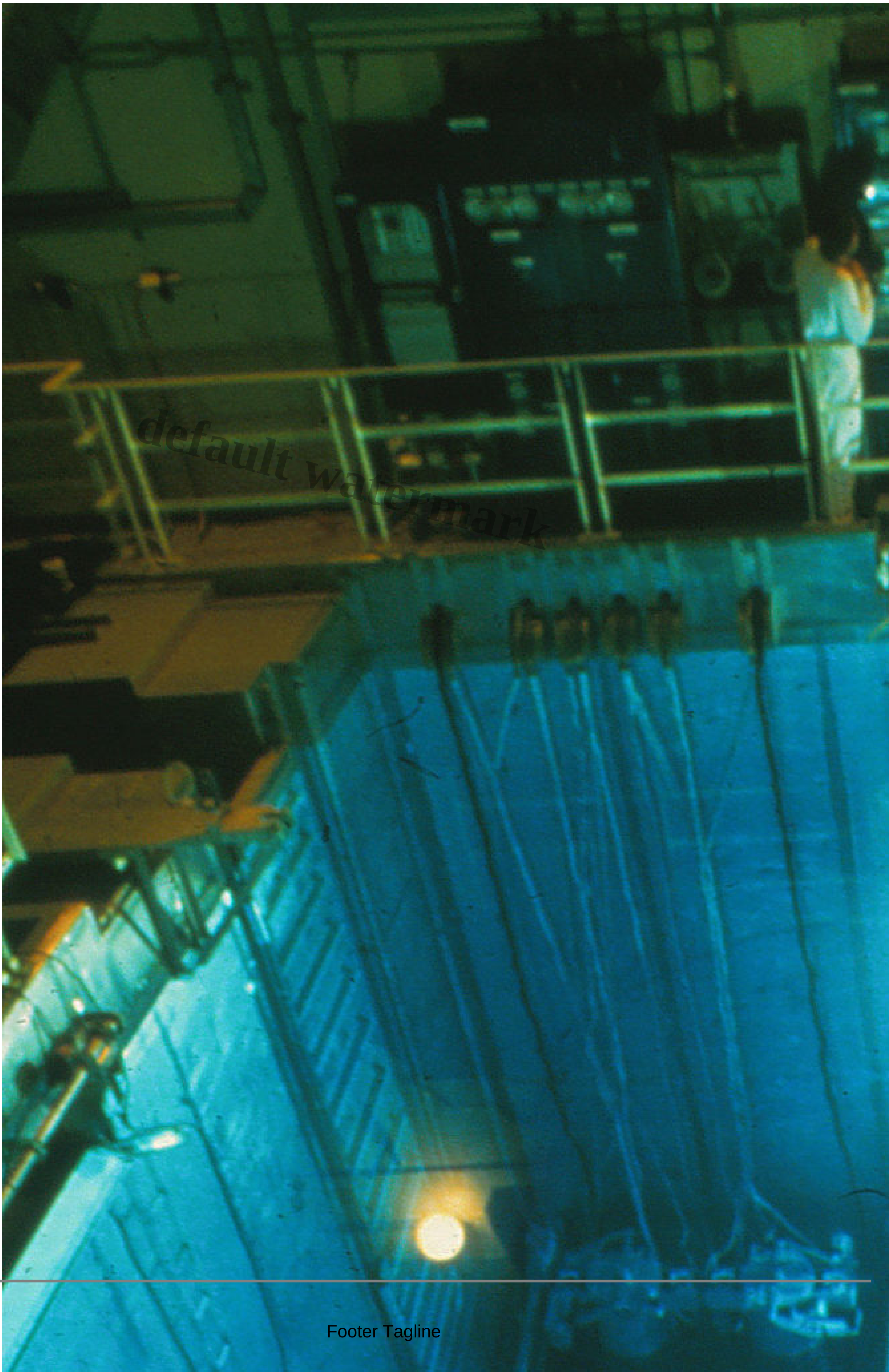
Hindsight is a wonderful thing but it is not to be confused with wisdom. Now back to 1988.

Charles Checked for Contamination after Dive

Charles Preparing for a Nuclear Dive



Diver lowered into Fuel Pool



Fuel Pool

Health Physics Technicians

Nuclear Diver Training in Swimming Pool

Reactor Pool.

Water is the key word to nuclear diving. A diving friend of mine once had a tee shirt saying â€œInstant Diver â€“ Just Add Waterâ€•.

Sounds obvious perhaps, but water is used extensively in the nuclear industry, not only for primary and secondary cooling but also for radiological shielding. The water used in the primary cooling and shielding systems of a nuclear power station never comes into contact with the outside environment due to the levels of radioactivity present in these systems. The secondary cooling water utilises a system of heat exchangers and is therefore totally contamination free. Secondary cooling water would come from a lake, a river, or, as in the case of Koeberg, the cold Atlantic Ocean.

The definition of nuclear diving is any underwater diving work performed in the areas of a nuclear facility where radiation exposure or contamination to the diver is possible.

A commonly used term in the nuclear industry is ALARA that stands for â€œAs Low As Reasonably Achievableâ€•. This means that while it is accepted that some workers at a nuclear facility will be exposed to radiation while performing routine maintenance tasks, this exposure is kept as low as possible and never exceeds the internationally set legal limits. Therefore, if a certain task has to be performed in the areas where water is being used as a radiological shield, then to remove that water to achieve this, would expose the workers to an unacceptable level of radiation. In addition, the time and expense of removal, handling and storage of the water for the duration of the job could run into many millions of Rands. The cost in lost revenue alone to shut down a power station the size of Koeberg is approximately R2m per day (1988 Rand value).

It is obvious that nuclear diving has numerous benefits for the industry that relate to both radiological controls and industrial productivity, the potential dangers that exist can be readily overcome by proper training, planning and supervision. Now with nuclear diving as an available option, new maintenance and modification projects can be planned to improve productivity that would otherwise have been more complex, or even impossible, to achieve. The ALARA principle in conjunction with the nuclear diving, serves to unlock the door to safe and efficient production.

The history of nuclear diving goes back to as early as 1963 at Big Rock Point Nuclear Power Station in the USA, when divers successfully effected repairs inside an irradiated reactor vessel, but it was not until the mid 1970â€™s that nuclear diving began to gain acceptance as a viable method of nuclear maintenance. Today the nuclear diving industry in North America has developed into a multi-million Dollar operation, with a number of large engineering companies specialising in this form of underwater work.

The actual diving conditions encountered by the nuclear divers are near perfect, with good lighting, excellent visibility, no currents, shining stainless steel pipes and fittings and warm water. Furthermore, the depth never exceeds 12 metres, allowing a diver to stay at the bottom for over 3 hours without the need to decompress. The only two limiting factors are the diverâ€™s exposure to radiation and radioactive contamination and the water temperature that can be in excess of 40 degrees Celsius where the divers are operating.

In a nuclear power station, the two locations where nuclear diving work is performed are the spent fuel and nuclear reactor pools. The spent fuel pool at Koeberg is situated in the fuel building adjacent to the reactor containment structure, and consists of a stainless steel lined pool 10 metres long, 7 metres wide and 12 metres deep, in which the spent fuel assemblies are stored. The spent fuel is stored in demineralised water to which boric acid has been added to a concentration of 2 000 parts per million. The water acts as a radiation shield and the boric acid as a neutron absorber thus preventing any chance of a critical reaction. The spent fuel assemblies must be stored for ten years after removal from the reactor, until which time as their radiation and heat release levels have decayed sufficiently to allow their transport to an off-site storage facility or fuel processing plant. The new fuel assemblies emit low levels of radiation and can therefore be stored dry. The reactor pool also consists of a stainless steel lined pool, where the reactor vessel is submerged during refuelling in the same water as that of the spent fuel pool. The water temperature is controlled by heat exchangers.

I will never forget my first trip into the inner sanctum of Koebergâ€™s containment building. By the time I had been through the numerous security and radiological checks and finally arrived at the edge of the reactor pool, I felt I had entered another world, one of science-fiction in the 21st century. The water filled pool that lay at my feet with its stainless steel walls and fittings and crystal clear water, was tinted blue by the boric acid and illuminated by powerful underwater lights, afforded a truly beautiful, if not awesome sight. The huge stainless steel lid of the reactor vessel had been removed for refuelling and a number of fuel assemblies could be seen through the water. If it were not for the water, the radiation levels where I was standing would have been extremely dangerous, but as it was, I received no more radiation than if I had spent the day in the sun on Clifton Beach.

I have been running a small research and maintenance diving unit for Eskom since 1977, and in 1984 I was approached to conduct a feasibility study into developing an â€œein houseâ€• nuclear diving capability for the Koeberg Nuclear Power Station. Koeberg consists of twin pressurised water reactors of Westinghouse design, with a total output of nearly 2,000MW, the second reactor having been commissioned by Eskom during the latter half of 1985. In Europe and North America, utilities operating nuclear power plants usually find it cost effective to contract outside expertise to perform nuclear diving work, but it was decided that due to the high cost and possible delays associated with flying a team of specially trained divers and diving equipment to South Africa from overseas, the expertise would be developed locally. The present day (1988) cost of flying a small team of nuclear divers, consisting of an engineer, a supervisor and three divers to South Africa for one week from the USA is estimated to be between R125,000 and R300,000 depending on whether overtime and weekend time is incurred.

Once the decision had been made to go ahead with the project, the equipment had to be ordered and working procedures written. After obtaining scraps of information both locally and overseas, I conferred with some Health Physics technicians from Koeberg for assistance in the drafting of a safety procedure for nuclear diving that contained both diving and radiation protection techniques. This document included exposure limits, precautions, limitations, the preparation of a contamination-controlled zone, pre-dive radiological surveys, diver dressing, diver dosimetry, diver post-dive contamination and exposure check and equipment decontamination.

The diving equipment, consisting of Kerby Morgan Superlite helmets and Viking dry suits with surface-to-diver communications and surface supplied air delivered via a surface control panel, was purchased. All equipment necessitated a smooth surface that was easily decontaminated after use. This was because, once the diver arrives at the surface in the diving cage after a dive, he inflates his dry suit to remove any wrinkles in the material. He is then hosed down with demineralised water while the diving cage is still suspended above the water, thereby removing any loose contamination. All the diving equipment is then dried and checked for contamination, using a sensitive radiation survey meter. Additional equipment required includes personal and remote dosimeters, temperature probes, diver operated closed circuit television and various tools. Once a new consignment of spent fuel from the nuclear reactor is placed in the spent fuel pool, the water temperature may rise above 35 degrees Celsius in which case a special cooling undersuit vest, loaded with crushed ice, may be used to prevent the divers suffering from heat exhaustion. An alternative method would be to use a recirculating water suit similar to those used in the West Coast diamond diving industry, but using cold rather than warm water for heat control.

It is the function of the Health Physics Group at Koeberg to ensure that any person working in an area where radiation or contamination is present, keeps his dose down to a minimum and does not spread any contamination outside a demarcated radiological controlled zone. To a nuclear diver, both radiation and contamination are potential problems. The type of radiation that would be encountered by a diver would be in the form of alpha, beta and gamma radiation. (Neutron radiation only occurs during the fission process, when the reactor is operating and therefore does not affect the divers, as diving work would only be performed during cold shut-down of the reactor.) Furthermore, as alpha radiation would only be present in the unlikely occurrence of a leak in the fuel assemblies and beta radiation is attenuated by the diving suit, the main source of radiation exposure to a diver would be from gamma radiation. Radiation exposure in the nuclear industry is similar to the radiation exposure received from such sources as medical X-rays or the sun. The energy waves pass into or right through the body or any other material in its path, but do not leave any radiation behind. The depth of penetration depends on the type of radiation and the material being subjected to that radiation.

Contamination, on the other hand, is radioactive material that can become fixed to a person or object. This occurs in debris such as dust or corrosion products that may be present in the water. If contamination gets onto the diving equipment or even onto the diver in the event of a leaking suit, then this contamination must be removed by health physics technicians. It is also important to control the spread of any contaminated water by careful monitoring and the laying down of disposable plastic sheets in the radiological controlled zones. Before the commencement of any diving operation, a pre-dive radiological survey is performed utilising a waterproof probe connected to a surface dosimeter. A diagram of the work area, showing the radiation profiles and water temperatures is then drawn up and a dive plan compiled. The close co-operation between the diving supervisor, divers, health physics technicians, medical personnel and maintenance engineers is essential at all times.

The divers undergo a thorough medical and radiological check before and after each diving operation and up to 12 dosimeters are placed on the diverâ€™s body, under the dry suit. In addition, a dosimeter, which gives off an audible alarm when a predetermined level of radiation is reached, is placed on the diver with a readout at the surface control panel for real-time radiation monitoring. From the time the diving team arrives at the work place, an hour or more may be spent in dressing the diver before he can enter the water. The diver is then lowered into the water in a specially constructed stainless steel cage, using an overhead crane.

Surface-to-diver communications are essential and the dive plan must be strictly adhered to, as the diverâ€™s position in relation to the radiation source is critical. For example, the Tenth Value Thickness (TVT) for gamma radiation in water is 62cm. Therefore, the radiation level 62cm away from the source is one tenth as strong as a the source and only one hundredth as strong as at the source, if 124cm away. Detailed records of each diverâ€™s radiation exposure are kept to ensure that nobody exceeds the annual whole-body legal dose limit of 50 milli Sieverts (mSv). The Sievert (Sv) is the unit used in radiation protection to measure the amount of radiation dose received by an individual. This unit also takes into account the possible biological effect produced by that dose, from the various types of radiation. A typical annual exposure for the main in the street would be between 1,0 and 1,5 mSv from such natural sources as cosmic and terrestrial radiation.

While the divers must remain clear of radiation sources, care must also be taken that the diving equipment is completely watertight, as some low level radioactive material may be present in the water. Any radioactive water that is ingested or absorbed through the pores of the skin, could therefore pose serious problems. Although modern dry suits are essentially watertight, careless maintenance or diver dressing procedures could cause the ingress of water into the dry suit or diving helmet. Besides the norma training and practical experience required of a commercial diver, a potential nuclear diver must pass an annual radiation workerâ€™s medical examination, be subjected to a whole-body radiation count using a sophisticated machine, pass an Eskom course on basic industrial radiation protection and be trained in the operation of the specific equipment to be used. In addition to the strict relations laid down regarding the maximum radiation dose allowed per diver per year, there are also quarterly, daily and hourly limits. These limits also vary, depending on the part of the body to receive the radiation exposure.

As Eskom presently employ only two commercial divers, additional divers are required to spread the dose received per diver during prolonged diving operations and to ensure that the individual diver-dose never exceeds the maximum regulatory dose limits. For this reason a team of divers from South African Diving Services (SADS) has been trained as nuclear divers. To date, Eskom and contract divers have performed a number of training dives both in a swimming pool and in Koebergâ€™s spent fuel pool, all of which have been completely diver-contamination free due to the great care taken in equipment preparation and diver dressing. A training dive in the hot water pool at Goudini Spa ear Worcester was also performed to ascertain the physiological effects of the hot water on the divers. The divers performed moderate physical exercise for over 45 minutes in a water temperature of 32 degrees Celsius with no ill effects. Eskomâ€™s appointed medical practitioner will be present during all nuclear dives in case the divers suffer from heat exhaustion or if other diver-related problems occur.

With the training complete, the first nuclear dive in South Africa was performed on 29 October 1985 in the spent fuel pool of Koebergâ€™s number two reactor, after over a year of preparation. The purpose of this dive was to perform a final check on the equipment and operational and safety procedures and to remove a dosimeter that had previously been accidentally dropped into the pool by a Technician. The water was uncontaminated and only very low levels of radiation were present in the pool. It is often said that the worst part of diving is the dressing and nuclear diving is no exception to this rule. The fuel building was hot and humid and by the time the overalls, plastic protective clothing, dosimeters, dry suit and diving helmet were in place, having been checked and re-checked, I was sweating profusely and very keen to get into the water so that the load on my shoulders from the weight of the harness and helmet could be alleviated.

Finally I was helped into the waiting diving cage which was then submerged. The rows of empty spent fuel racks lay before me and at the sides of the pool, a complicated array of stainless steel pipes, valves and mechanical fittings could be seen, sparkling and clean in the bright underwater lighting. The surface-to-diver radio crackled into life and the surface operator began to relay messages about the route that I should take once I left the confines of the diving cage. I made some fine adjustments to my buoyancy, removed the safety bar from the cage and stepped off to hang suspended above the spent fuel racks.

I cautiously depressed the air purge button on the suit and drifted down the side of the racks to the bottom of the pool. On the pool floor was a small quantity of irradiated corrosion products. In a newly commissioned facility such as Koeberg, these corrosion products should not pose a problem but in an older facility they can be a source of both radiation and contamination so, for the purpose of the exercise, I tried to hover about half a metre above the floor, while relaying my observations to the surface. On my way back to the diving cage I retrieved the abandoned dosimeter that was balanced precariously on the edge of a fuel rack. It was indeed fortunate that it had not fallen into the rack as retrieval in that case would have been. more difficult.

On arrival at the surface again, there was a flurry of activity. The cage was held above the water and the diving equipment hosed down. Once â€œashoreâ€• the suit and helmet were thoroughly dried and checked by the health physics technicians for contamination. The diving equipment was then slowly removed and the dosimeters sent away for checking. The first nuclear dive to be performed in South Africa was over, with very little radiation exposure and no contamination having been recorded

There is probably nothing more frustrating than putting a considerable amount of time and effort into the development of a technique and then never making use of the expertise. With nuclear diving, in a country with a relatively small nuclear industry such as South Africa, just such a situation could easily occur. The most significant nuclear diving task to be tackled by Eskom to date came from a totally unexpected source. I received a request from the Atomic Energy Corporation (AEC) to assist them in a maintenance project at their Safari One research reactor at Pelindaba near Pretoria. This reactor had been running almost continuously since it was commissioned 23 years previously and now required maintenance that could only be performed with the reactor pool drained of water.

During the nuclear fission process within a reactor, neutron radiation bombards the metal components within the reactor pool thus activating the metal. Once the reactor is shut down, this neutron activity ceases but the metal components have become activated and themselves release radiation, usually in the form of gamma radiation. The radiation levels of these activated components diminish at different rates, according to the particular half-life of that metal. The half-life is the time that it takes for the radiation level to drop by 50%. The half-life of a material can range from a few milliseconds to millions of years.

To drain the reactor pool introduced a problem with the radiation levels, as although the pool lining and piping were made of aluminium, and consequently had a relatively short half-life of approximately 8 minutes, there were stainless steel flexible bellows in the piping with the half-life of approximately 5 years. This meant that in the time allocated for the completion of the task, the radiation dose rates of the stainless steel components would still be unacceptably high in air. The plan was therefore, for the AEC technicians to remove as many components as possible by means of remote tools before the diving team arrived on site. The divers would then remove 112 stainless steel bolts from the bellows and assist the surface team to lift the bellows free of the piping, using an overhead crane and place them in a water filled storage area adjacent to the reactor pool, where the water level could be maintained even when the reactor pool was drained. During this entire operation, the stainless steel bellows were never to break the surface of the water.

After a number of meetings in Cape Town and Pretoria, a detailed plan of operations was drawn up and special tools designed and fabricated. With the reactor at cold shutdown, a detailed underwater radiological survey, using remove sensors, was undertaken. The contract dose rate on the â€œhotâ€• bellows was found to range between 920 and 1500 mSv / hour with the background radiation levels at between 1,0 and ,15 mSv / hour. However, due to the shielding effect of the water, the radiation level to the diverâ€™s body about 1,25 metres away from a radiation source emitting 920 mSv / hour would only be 9,2 mSv/hour. As most of the diving work would be done from a diving cage, the diverâ€™s position relative to the bellows and the side of the reactor vessel could be carefully controlled by the surface team.

Although the dose rates were a known factor, the diver-man-doses for the operation were not, as the time to be spent on the job and the exact distance that the diver needed to be from the workplace could not be determined in advance. As a result, it was decided to use the full team of nuclear divers, thus keeping the individual diver job dose to a minimum as required in the ALARA principle. Fortunately it was possible to lower the water temperature from 26 to 18 degrees Celsius for the operation using the heat exchange system, thus eliminating the problem of heat exhaustion.

On arrival at Pelendaba, the nuclear diving team was shown the reactor and briefed in detail by the AECâ€™s head of Reactor Operations. The AEC had put a lot of effort into making special spanners and lifting tools to ensure that the divers remained as far away from the radioactive bellows as possible. A model of the flanges had been constructed to enable the divers to familiarise themselves with the correct operation of the tools before they entered the water. The full team consisted of five divers, two supervisors, six health physics technicians and the head of Reactor Operations. As a team, it was imperative that everyone concerned had a thorough understanding of the entire operation. Good team work was essential at all times to ensure an efficient and safe operation.

The final pre-dive radiological pool survey was completed and the diver dressed. Firstly dosimeters for monitoring radiation exposures were attached to the diverâ€™s hands, feet, legs, head, back and chest. An additional digital radiation meter with a remote surface readout and pre-set audio alarm was installed. Next the dry suit and diving helmet went on and the diver to surface communications, air pressures, and emergency bail-out system were checked. The tension mounted as the diver was helped into the diving cage and slowly descended towards the clear blue water, well illuminated by powerful underwater lights. While the diving supervisor controlled the path of the diving cage in the water, the health physics technicians kept a watchful eye on the digital radiation meter.

The diver moved into position over the first bellows flange and started to work. The first Milli Sievert was registered on the meter. An additional probe was utilised to move around the pool, near the diver, in order to keep him away from areas of unnecessarily high radiation levels. Often the health physics technician would ask the diver to move his legs or body a few centimetres to keep the dose rate as low as possible. After each dive, any problems were sorted out and new ideas implemented.

Finally the task was completed from the diving point of view, although many man hours of work lay ahead for the AEC engineers, scientists and technicians. During the four day operation, 9 dives were undertaken totalling 22 hours. The total man-dose for the operation was far lower than envisaged, being only 3,8 mSv for the entire operation with a maximum accumulated exposure to an individual diver of 0,8 mSv representing only 1,6% of his yearly permissible dose. A dose of 0,8 mSv can be compared to the radiation received from natural causes every year of between 1.0 and 1,5 mSv.

If, after reading this brief introduction to nuclear diving, you come away with the feeling that it is a hazardous occupation, reflect on your fist diving course, when you were told about all the dangers associated with recreational diving. Decompression sickness, air embolism, oxygen poisoning, shark attack and drowning, to mention just a few. Why then do you dive? Because you learnt that with the correct equipment, training and pre-dive planning, diving is a safe and enjoyable sport. The same apples to nuclear diving. The dangers present are only POTENTIAL dangers, and with the correct approach, will never become real dangers. The safety standards in the nuclear industry in South Africa are as high as anywhere in the world and something of which we can be justly proud .

Nuclear diving is the result of the successful merging of two specialised disciplines, those of commercial diving and the nuclear industry. What future has nuclear diving in South Africa? Once the reserves of fossil fuels such as coal, diminish, and the air pollution of large coal burning power stations increases, there will be added incentives to go nuclear. This, plus South Africaâ€™s increasing dependence on local technology, points to the fact that nuclear energy and therefore nuclear diving are here to stay.

Category

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