Long before the advent of the atomic bomb or nuclear power, mankind lived in a radioactive world. Our planet is made up of the nuclear debris of exploding stars, consisting of both the stable elements and also some long-lived radioactive isotopes of uranium, thorium and potassium. We also continue to be bombarded with cosmic rays from our own sun and from distant galaxies. Our very bodies carry a mix of radioactive materials imparted to us from Mother Nature. Added to this mix of radiation is the newer manmade nuclear radiation from sources such as nuclear weapons and of course, nuclear medical procedures.

The nuclear industry is very mindful of the potential radiation hazard that lies at the heart of its existence. So much so that it is probably the only industry that for routine operations internalizes its external costs. The industry takes great care to control radiation doses to the public and to the environment, and also to monitor these impacts. Such doses are much lower than those from natural sources and are well under regulatory limits.

Why generally do we fear this whole business of nuclear power? The root cause, no doubt, lies in how that power was first shown to the public so horrifically, with great loss of life and utter destruction, in the atomic bomb blasts in Japan, at the end of the Second World War.

The nuclear bomb mushroom cloud image still stalks our thoughts, even with the passing of over 70 years from the event. We still fear the seemingly unknown. At the inception of electric power, more than a century ago in the late 1800's, the then new-fangled electric lights induced public fear, and produced an ardent anti-electric power group. They were so opposed to the new power that they demonstrated in Times Square in New York, about how deadly the new electric power was. They even electrocuted a dog in public, to dissuade people from using electricity. We may smile at such fears now, despite the fact that thousands of people do die each year from electrocutions.

Nuclear power and associated radiations do have their risks, but they need to be put into perspective.

There are controls and procedures in place to keep the usage of electric power safe. The same is true of nuclear, which operates under a strict regulatory environment. Very comprehensive international standards are in place. The end point of determining possible harm to man and the environment is knowledge of the radiation dose incurred.

Dose limits are set internationally, for both radiation workers and the public. All aspects of the operation of nuclear facilities are controlled, to keep doses as low as possible and under relevant limits. Nuclear facilities are subject to a nuclear operation license, which specifies operating conditions.

Dr Cairns Bain has an MSc in nuclear physics and a PhD in coastal oceanography. Before retiring from the South African Nuclear Energy Corporation (Necsa) he was Chief Scientist dealing with environmental radiation monitoring and public dose assessment. Dr Bain carried out site assessments at the inception of the Koeberg nuclear power station and at the site of the Vaalputs radioactive waste repository. Since retiring he has carried out reviews of aspects of the radiological assessment of the new nuclear power station sites in South Africa.
Dose Probability

Radiation dose limits are not based on short term acute effects, but on long term 50 year accumulated effects. Short term, acute exposure to radiation levels of above 1000mSv can result in skin reddening, hair loss and vomiting. Short term means; hours to weeks. Legal Limits are instituted to protect people from probabilistic long-term effects, such as cancer, and not from these acute effects which require much higher doses, which people would normally never encounter.

This can be compared to the chances of contracting cancer from cigarette smoking. Just a few cigarettes a day for a few months would be very unlikely to result in lung cancer, but more smoking over many years results in a much more probable chance of getting cancer. However, we all know of people who have smoked heavily for years but have not suffered cancer.

As with nuclear radiation, the issue is not the certainty of the effect but rather the linkage to a mathematical probability. The basis of legal radiation limits is based on low annual levels of radiation, calculated such that the chance of any effect being observed in people is very small.

Internationally, although the dose limit to the general public is set at one mSv per year, the limit set for the public living around nuclear facilities, such as nuclear power stations, is set at a fraction of this limit. For South Africa this limit is set at one quarter, or 0.25mSv per year.

Comparison of the values in annual dose limit and those of acute effects shows that the legal dose limit for the general public is a factor of 1000 lower than that required for the onset of initial acute effects. For the public surrounding a nuclear facility, the safety factor is even greater, being factor of 4000 lower. To state the obvious; it is not ‘dangerous’ crossing the limit.

<table>
<thead>
<tr>
<th>ANNUAL PERMISSIBLE DOSE LIMITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>RADIATION WORKER – 20 mSv per year</td>
</tr>
<tr>
<td>GENERAL PUBLIC – 1mSv per year</td>
</tr>
<tr>
<td>PUBLIC LIVING NEAR A NUCLEAR FACILITY – 0.25mSv per year</td>
</tr>
</tbody>
</table>

These legal limits are over and above the Background Dose constantly received from the earth itself and from the stars above us.

ACUTE RADIATION DOSE EFFECTS

<table>
<thead>
<tr>
<th>EXPOSURE DOSE</th>
<th>SYMPTOMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000mSv</td>
<td>Mild nausea, vomiting, anorexia, fever.</td>
</tr>
<tr>
<td>2000mSv</td>
<td>Mild to moderate nausea, vomiting, anorexia, fatigue, bleeding.</td>
</tr>
<tr>
<td>4000mSv</td>
<td>Moderate to severe symptoms with 50% mortality after 5 weeks.</td>
</tr>
</tbody>
</table>

A person would never receive a dose this high unless they were involved in a serious accident inside a nuclear plant.

In practise the annual limit for radiation workers and the public is incurred evenly throughout the year, but it can happen that the annual dose is reached in just one short event in the year. As a result, a radiation worker dose limit is defined as an average over a 5 year period. A Radiation Worker dose limit is 20mSv per year.
Perspective on Surrounding Radiation Dose

There is no such thing as zero radiation dose - we live in a naturally radioactive world. On average, over our planet, each person is exposed to 2.5 mSv per year, with contributions coming from naturally occurring radioactivity in soil, the food we eat, the air we breathe, cosmic radiation from outer space and from medical procedures. This average value varies widely, due largely to different geology, food types, altitude of towns and the level of medical procedures. The air is thinner at higher altitudes, thus the flow of cosmic rays from outer space delivers a higher dose.

So, the cosmic radiation background of 0.25 mSv per year, at sea level in Cape Town, about doubles to 0.50 mSv per year in Johannesburg at an altitude above 1700m. Going higher, like travelling on a transcontinental jet from Cape Town to London return, will give you a cosmic ray dose of about 0.05 mSv. International air flight crew who fly 700 hours per year receive a dose varying from 2 to 5 mSv, which is a factor up to 10 times higher than the annual average radiation dose for workers at Koeberg nuclear power station.

Interestingly instead of an increase in cancer, there is some indication of a slightly lower incidence of cancer at Ramsar but statistics on such a small population are uncertain. Similarly at Yangjiang, in China, where there is a thorium concentration exhibiting three times the world average background, no negative effects are seen. Guarapari Beach in Brazil has dose hot spots as high as 175 mSv per year.

So radiation exposures are an everyday natural reality. If we turn back to the dose limits for people near nuclear facilities, of 0.25 mSv per year and then inspect the data from Koeberg and Pelindaba for the actual dose levels observed, we realize that they are in fact extremely low.

The biggest anomalies associated with natural radiation are from the terrestrial sources associated with different geologies and associated minerals. A place called Ramsar in Iran, near the Caspian Sea, holds the world record for the highest household dose of 250 mSv per year. There, in hot springs, the radioactive material radium, which is a decay product of uranium, had precipitated in limestone, which was then used for building. The average dose for the 2000 persons living in the area is 10 mSv per year, which is a factor of ten above the public dose limit.

Most nuclear power stations are sited on the coast or on the banks of a large river or lake.

### ANNUAL DOSES AT SOUTH AFRICAN NUCLEAR FACILITIES

<table>
<thead>
<tr>
<th>Facility</th>
<th>Annual Average Worker Dose mSv</th>
<th>Annual Discharge Dose per Pathway mSv</th>
<th>Factor Below Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Koeberg: Nuclear Power Station</td>
<td>0.52</td>
<td>0.0021 0.00018 0.0023</td>
<td>109</td>
</tr>
<tr>
<td>Pelindaba: Nuclear Energy Corporation</td>
<td>0.62</td>
<td>0.0063 0.00033 0.0096</td>
<td>26</td>
</tr>
</tbody>
</table>


Radiation Dose

A Sievert is a measure of radiation dose which is absorbed by people. This is different to the total amount of radiation emitted by radioactive objects which is measured in Becquerel's (Bq). The Sievert was named after Rolf Sievert, a Swedish physicist who was a pioneer in the science of radiation physics and protection. In 1964 he founded the International Radiation Protection Association (IRPA). The Sievert (Sv) is a rather large dose, and for most daily purposes the milli Sievert (mSv) is used, being 1/1000 of a Sv.

One can go even smaller and use the micro Sievert, which is 1/1000 of a mSv. It is written as μSv.
Dose Estimations and Environmental Monitoring

How does the public, or the environment, receive radiation from a nuclear facility under normal operating conditions? In a nutshell, a nuclear facility is legally allowed to discharge a certain very small amount of radioactive material into the environment; either to the air or to water bodies. Such discharges can result in the public incurring a radiation exposure either directly, or by various pathways such as the air they breathe or the food they consume.

Because of the potential radiation hazards of operating a nuclear power station, their operating license requires measurements and monitoring of any liquid or gaseous discharges to the environment. Such measurements must prove that they are operating safely within the limits set. The routine annual discharge limits allow for small operational mishaps but not for emergency-scale accidents which are handled separately. Solid radioactive waste is stored safely on the site before being transported to a designated nuclear waste site.

During routine operation of a nuclear facility the only way the public could receive any radiation exposure is from the allowed discharges of liquid and gaseous wastes. Gaseous discharges are subject to strict control, including the last stage which passes via very efficient particulate filters. Radioactive liquid discharges too are strictly controlled and are generally mixed with cooling water from a steam condenser unit, before being released into the sea via a discharge canal or pipeline. The quantity and type of radioactive material discharged is accurately monitored and measured. The quantities are logged hourly, daily and monthly; as specified in the operating license.

Because of the routine potential for very small amounts of radiation to be released from a nuclear power plant, there exist strict legal licensing conditions which plant operators have to adhere to. As a result, regular monitoring takes place and so radiation figures are known to an incredibly high degree of accuracy, as specified in the operating license and evaluated with comprehensive dose assessment models. Such models integrate the possible minute daily human exposure pathways to yield the annual accumulative dose on which the legal limit is set.

These figures are so low as to be inconsequential to people, in comparison to natural background radiation coming down from outer space and coming up from natural radiation in the ground. We live in a naturally radioactive world.