The Incident at the FUKUSHIMA Nuclear PLANT - March 2011

The first part of these notes were written by 18:30 on 12th March 2011. Subsequent updates follow as shown below:

- 17:00 on 13th March – section 9.
- 23;00 on 15th March – section 10.
- 19:00 on 17th March 2011 – Section 11
- 23:00 on 19th March 2011 – section 12
- 23:00 on 21st March 2011 – section 13

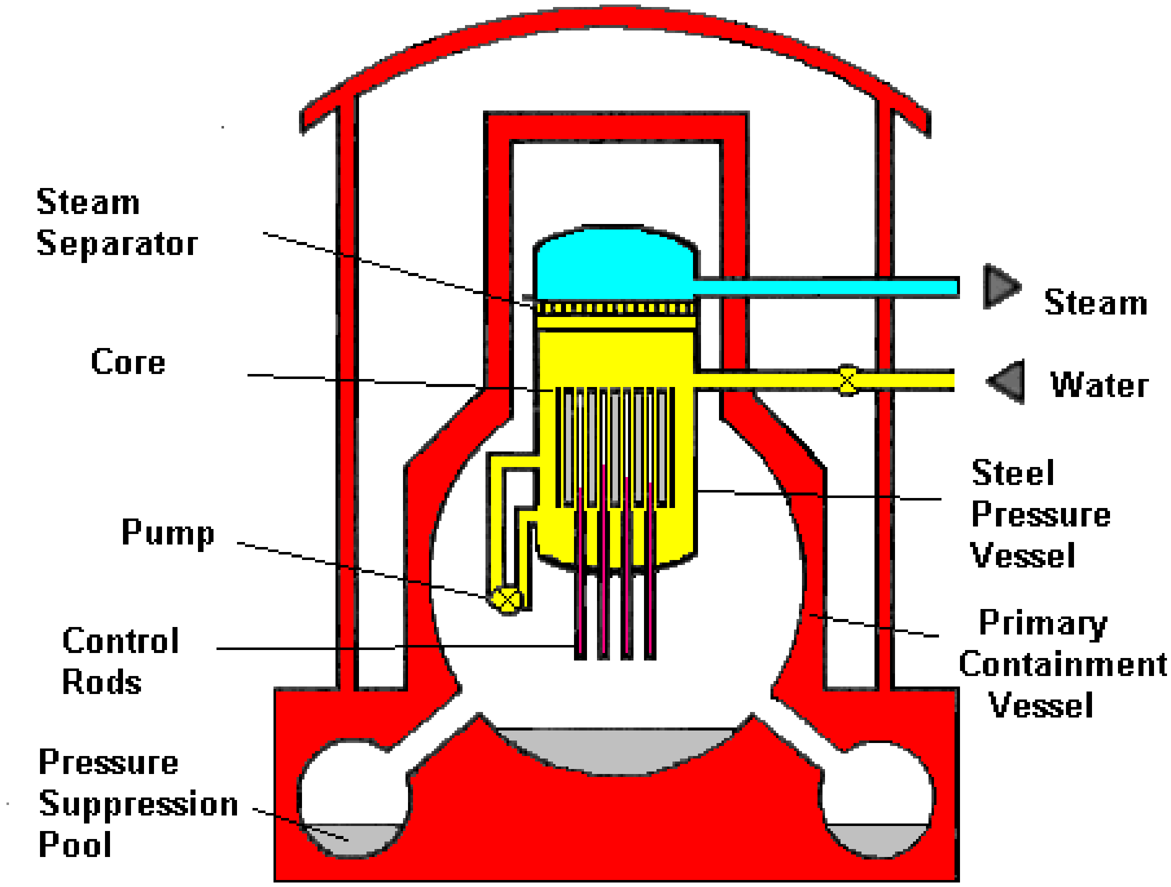
For clarity and ease of identifying updates, each update is written in a different colour.

1. Background

During my lectures on Nuclear Power a month ago, there were some types of nuclear reactor which I did not cover this year as I had less time than previously. I pragmatically decided not to cover the Boiling Water reactor – a derivative of the Pressurised Water reactor as this type has never been built in the UK, and neither are there plans to at the present time. Despite this I did include a few supporting summary notes from last year.

However, in view of the Fukushima incident it is perhaps relevant to summarise what it would appear has been happening. Indeed there has been much incorrect information put out by the media. Thus they referred to "flying in coolant". Why on earth would any one do this when the coolant they are referring to is ordinary water. What they may have meant was equipment to assist with cooling which is something very different altogether.

Information is still incomplete, but this is my analysis for information I have obtained to date. It is a fast moving story and things may change – but the following is the situation as of 18:30 on 12th March 2011.



A Boiling Water Reactor. Notice that the primary circuit steam which may become radioactive in normal operation is passed directly to the turbines.

2. A basic introduction to the BWR

Unlike a Pressurised water reactor, a Boiling Water Reactor actually allows the water in the primary cooling (i.e. reactor cooling circuit) to boil and as a result operates at a pressure of around 70 bar rather than around 160 bar in a normal PWR. However, there are major differences.

BWRs are the second most common reactor in the world although in Japan it is the most common reactor with 30 units in operation as opposed to 17 PWRs (see table below)

Thus unlike in a PWR, the primary coolant passes directly through the turbines rather than relying on heat exchangers to raise steam for the secondary turbine circuit. As a result the BWR has the potential of being a little more efficient thermodynamically than a PWR.

In all nuclear power plants there is the possibility of a burst fuel can – usually no more than a small pin prick which may allow gaseous and/or liquid daughter products from the nuclear reaction to circulate in the primary circuit. In the case of the British Design (MAGNOX and Advanced Gas

Cooled reactors) and the Canadian design (CANDU), such defective fuel elements can be removed while the reactor is still on line and generally any contamination within the primary coolant is very minimal.

In the case of the PWR and BWR reactors, however, refuelling can only be done at routine maintenance shutdown – typically up to 21months apart, and so the primary coolant will tend to become radioactive from any fuel cladding issues. In the case of the PWR, such mildly radioactive cooling water is kept within the containment building and the water passing through the turbines is not radioactive. In the case of a BWR as at Fukushima-Daiichi-1 the slightly radioactive cooling water will pass through as steam through the turbines such that the turbine hall may be an area of slightly raised radiation levels.

3. Fukushima Nuclear Power Plants

At Fukushima there are ten separate reactors in two groups making it one of the highest concentration of nuclear plant in the world. The Daiichi group has six separate reactors which were commissioned between March 1971 and April 1979 whereas the Daini group located some kilometres to the north has four commissioned between 1981 and 1986. The affected plant was Fukushima-Daiichi-1 which is the oldest and scheduled to reach 40 years of operation later this month. This reactor is the third oldest reactor still operating in Japan and would have been scheduled to close shortly. It has a gross capacity of 460 MW and a net output of 439 MW (i.e. after power has been taken for pumps etc). Most of the other reactors are larger at 760MW each for Daiichi - 2 to 5 and 1067MW for the other five reactors.

The performance of Daiichi-1 has been fairly poor with an average annual load factor of just 53% compared with several at the Daini complex at well over 70% and Sizewell B with a load factor of 86%

4. Control of Nuclear Reactors and shut down phase 1

In many reactors the neutron absorbing control rods are held by electro-magnets and in the event of an incident (or power failure) will automatically fall by gravity. In the case of many BWRs and particularly the early ones, the control rods are driven up into the reactor and this will take typically around 5 – 7 seconds to complete. The attached table demonstrates that while some reactors continued throughout the quake, many shut down automatically as they were intended to do and this part of the phase was completed successfully.

You will remember from the lectures that it is quite difficult to sustain a nuclear reaction within the core and sufficient neutron density is required and also these must be of the slow moving neutron type for which moderators are needed. The purpose of the control rods is to absorb neutrons and thus shut down the reaction. Thus all the affected reactors shut down automatically as planned.

5. Aspects of the Incident – the early stages.

The second part of the incident is also something which I only covered briefly and that was the issue of radioactive decay. While it is clear that in all the 11 reactors which shut down automatically as soon as the earthquake hit, it is important to remember that this radioactive decay process still emits heat typically around 5 – 8% of the full output power during the first 24 hours falling to around 1% after a week and declining further thereafter. Thus it is critical that the cooling water circuits continue for several days to remove this residual heat.

In a MAGNOX reactor the heat output during operation is around 1 MW per cubic metre – which would be the equivalent of boiling a litre of water with a 1 kW element in the kettle. The analogy would continue that if the kettle switched off when the water boils the heat loss would be such that the kettle would loose heat and as long as the element remains covered, no problem would arise. However, imagine that the electricity does not turn off completely but still continues at say 10% (i.e. 100 W), this would be more than sufficient to keep the water boiling and if the water level was not continually topped up as the water boiled then the element would be exposed and fail. This is what effectively happens when a nuclear station is shut down so cooling is critical

In a boiling water reactor, the power density is nearly 100 times that of a MAGNOX reactor so in normal operation the heat generation is 100 times as will also be the decay heat generation, and at 10 kW (in the case of the kettle analogy) still generated after shutdown this potentially could cause the element to melt.

Notice this condition is much more critical in PWR and BWR plant compared to the British gas cooled reactors (MAGNOX and AGR).

In the case of FUKUSHIMA-DAIICHI-1, as with all similar situations which may occur with a turbine trip, pumps will automatically cut in to keep the cooling water circulating. However, with the simultaneous shutdown of 11 separate plant simultaneously and also a similar capacity of normal fossil fuel power stations, there was a substantial loss of power across Japan meaning there was insufficient power available to be drawn for cooling not only for this reactor but for all other 10 reactors which tripped simultaneously.

There are emergency procedures which then automatically cut in by drawing power (if necessary from batteries) until diesel or gas generators cut in to provide local emergency power. It would appear that such generators did indeed cut in and provided power for at least 20 minutes – some reports say 1 hour, but then some of these failed – either because they were knocked out by the tsunami, or the necessary distribution was so affected by the tsunami.

As it appears that the emergency core cooling failed as least in part if not in full, the temperature of the water/steam in the pressure vessel will rise and if this continues more water will convert to steam which occupies 1700 times the volume causing an increase in pressure in the circuit. Pressure vessels will be designed to withstand pressures at least 50% above normal operation and may be 100% or more above, so a small rise is of no consequence, but it this does continue to rise, then it is important that this pressure is released and it is probable, although this needs to be confirmed, that steam (remember this is radioactive because of the design of BWR) will be released into the containment building. This is planned in such an emergency and is not, by itself a serious consequence. In some BWR, there is a condensate suppression pool at the bottom as shown and this will tend to condense some of the steam now in the containment building.

Remember that in PWRs and BWRs small changes in volume accompanying changes in temperature can lead to significant changes in pressure – whereas in the gas cooled reactors the changes in pressure with changes in volume / temperature are less marked.

6. *Reports of fires at power stations*

In the early hours of the disaster there were reports of fires at power stations, but information was sketchy and it was not clear whether this referred to fires in the turbine hall as does happen in fossil fuelled power stations – e.g. a few years ago Tilbury coal fired station was so affected. Within a turbo generator, hydrogen is used for cooling the generator as it is a particularly good conductor of heat. A hydrogen leak here could start a fire and/or an explosion. Whether this was the cause of the explosion is not known.

Hydrogen build up

If hot steam is released and it comes into contact with some hot surfaces, the steam can split into hydrogen and oxygen. This hydrogen could be the cause of an explosion as it was at the Three Mile Island incident where there was an explosion which, despite the core becoming uncovered was entirely contained within the containment building.

In most PWR and BWR nuclear power stations the containment building is dome shaped as this will withstand much higher pressures in the event of an explosion. Indeed Sizewell B has two independent domes. However, at Fukushima, the building appears to be cuboid, and it is not clear whether the containment building was within the building which failed and remained intact, and the actual building seen to fail being a shell covering the large space needed for cranes etc or whether it was the containment building itself which seems odd from its shape.

7. What then happened?

There indeed was an explosion as was seen from TV pictures, and this is likely to have been a hydrogen explosion. There is the possibility it could have been a structural collapse as a delayed effect of the earthquake – remember the twin towers in New York stood for some time after the terrorist attack in 2001 before they collapsed. However, the pictures as far as I could seen did suggest a small flame which would make hydrogen more likely. Once again this by itself – which ever is the case - is not overly serious and there were reports immediately afterwards that radiation levels were falling.

However, what is critical is the integrity of the pressure vessel. Later reports suggested that this was intact, and if this is so then the situation is likely to be recoverable, albeit with the reactor deemed a write off, but since it was almost at the end of its life (probably within next 12 months anyway) this would not have much of a financial impact.

If the pressure vessel integrity is compromised, and that is far from clear as I write at 18:25 on 12th March, then that is more serious, and there may be a melting of the fuel, but there can then be no nuclear explosion as the fuel is at far to low an enrichment and the moderator has been lost anyway.

However. At 18:20 the World Health organisation said "the public health risk from Japan's radiation leak appears to be "probably quite low". This suggests that the vessel is still intact:

Care must be taken on how subsequent cooling is attempted as if water is used and it contacts with very hot fuel cladding (Zirconium), then more hydrogen could be produced leading to a further chemical explosion which might lead to a further leak of contamination.

Do remember that radiation is generally of little consequence, but contamination is something over which we should be concerned.

8. *Consequence of Earthquake on UK energy*

With 11 reactors in total tripped, it will take some time to bring them all back on line and Tokyo Electric Power Company TEPCO is planning to run its fossil fuel plant more than normal which will mean an increase demand for oil and gas (Japan has limited coal generation).

Already there are moves in the financial markets seeing oil prices likely to rise as demand rises at the same time as the Middle East problems. Russia has already been approached by Japan for more LNG shipments at a time when LNG shipment prices are also rising, and since the UK is increasing dependent on energy imports this could see significant price rises in wholesale electricity prices in the UK in the near future.

9. *Update on 13th March 17:00*

Consultation of various further information and including the IAEA – Webpage over the last 18 hours allows an update.

9.1. Cause of Hydrogen Build up in Fukushima – Daiichi 1 reactor.

The most probable cause of this is not a hydrogen leak in the turbine hall which may have caused a fire in the turbine hall elsewhere, but as a result of the pressure venting from the reactor vessel. It would appear that the top of the fuel elements and or systems above in the reactor vessel came uncovered and this hot metal, particularly if it were the fuel cladding zirconium would have reacted to split the steam. This by itself is of little consequence.

However, the build up of hydrogen within the cuboid building was something that could ultimately result in an explosion as indeed happened. The alternative would have been to have regularly releasing the hydrogen and steam from the building minimising the build up.

When the explosion occurred – reports were of a massive or huge explosion, but I have rerun the video several times, and it can only be classed as small to moderated, and what appeared to be dramatic was the simultaneous steam release and the debris from the collapsing building. [Remember the very very large plumes of smoke and dust when the twin towers collapsed in 2001 – this was very very minor in comparison]. That it was a small explosion is confirmed by the higher detail images of Daiichi -1 available today showing the reinforcement steel intact and undistorted. Had the explosion been large then this steel would either have disappeared or been bent outwards, neither of which appear to be the case.

9.2. The integrity of the Pressure Vessel

The explosion clear took place around the pressure vessel and the fact that the cuboid shell gave way probably helped to avoid damage to the pressure vessel itself. All evidence indicates that this is the case - the very short burst of radiation which then fell, and the very limited amount of contamination on the population.

The News reports are confusing in references to radiation and contamination. Radiation decays rapidly with distance and even a short distance away from the plant such as 1 km direct line of sight would be adequate to attenuate the level to safe level even in the most intense situation. One can walk away from radiation, and if one is irradiated such as when having an x-ray it stops immediately the source is switched off or the person moves out of the critical area. Contamination on the other hand is another matter, as dust particles which might be radioactive will continue to irradiate a person unless the contamination is removed. Thus stripping off clothing with contamination is all that is needed to protect a person from health effects ***unless*** the contaminated particle is either ingested or breathed into the lungs. It is for this reason that larger exclusion zones than required to limit impacts of radiation are set up.

9.3. Critical Unanswered Questions

The nuclear plants all shut down safely or continued operating normally immediately after the earthquake, despite the fact that in the BWR the control rods have to be driven up rather than falling gravity in most designs. The standby by generators appears to have started when the grid electricity supply failed as they should [although this still needs to be confirmed], and some reports suggest that they ran for 20 minutes – others for up to an hour before failure. However, was this failure to continue cooling:

1. a failure of the generators .
2. the generators being affected by the tsunami, bearing in mind the station is close to the coast,
3. a failure in the water supply as there are severe water shortages reported in the area.

Of these three, the first seems unlikely as there is now a second and possibly third plant at the Daiichi complex now suffering similar problems and it is improbable that all back-up generators (and there are typically at least 4) failing at all the plants.

Since all the plants are parallel to the coast, then option (2) is possible, but why then contemplate using seawater as ordinary water would be far less corrosive of the plant. The strong likelihood is that (3) is the primary cause, although option (2) may also have figured as a partial cause.

9.4. Fukushima-Daiichi-1 present situation

All evidence points to the main pressure vessel being intact and cooling with sea water is now (16:00 13th March) is being pumped in to keep the core covered, In addition boron is added to this water as this is a neutron absorber assist further.

Using sea water is an odd solution as one would normally use ordinary water and the use of sea water does seem to reinforce the issue of option (3) being the primary cause of cooling failure. Using sea water, which is corrosive would make the plant unusable ever again

The Fukushima-Daiichi-1 plant is within 2 weeks of being 40 years old and was due to close shortly (within next 12 months or so) and so the decision to use sea water will have limited consequences on the future of the plant.

9.5 Other incidents. 17:00 March 31th

The situation is somewhat confused with different agencies, e.g. BBC, IAEA, Bloomberg Press etc, reporting different things. However, what does seem consistent is that

Fukushima-Daiichi-3

1. There appears to have been a similar loss of coolant at Fukushima-Daiichi-3 reactor close to the one previously causing concern. This is a larger reactor with a gross capacity of 784 MW and a net capacity of 760MW. Once again steam has been released from the pressure vessel and this probably may contain hydrogen again. With the experience of Reactor 1, the operators may try to release the build up of gas from the cuboid building to minimise the risk of an explosion, but this will almost certainly cause the release of some small amounts radioactivity and/or contamination.

   Remember that as BWR's and PWR's cannot replace defective fuel elements during operation, the primary cooling water circuit will almost certainly have contained some radioactivity/contamination before the incident started – unlike the situation in a MAGNOX, AGR, or CANDU reactor.
2. This reactor is 37 years old this year and the decision to use sea water as a last resort would only shorten its life bay a few years.
3. There are reports that this reactor is fuelled with mixed oxide fuel (MOX) which is a mixture of Uranium oxide (4-5% enrichment) with some plutonium which has been obtained either from reprocessing or from decommissioned nuclear weapons.
4. It is not clear what effect this mixed oxide fuel would have in a worst case scenario where the pressure vessel was ruptured. The primary source of contamination would be from the daughter products from the nuclear reactions, and the radiation issues arising from any plutonium would normally be relatively small compared to these. On the other hand there may be more significant chemical hazards.
5. There are reports of a possible faulty valve and or gauge, but the full significance of this cannot be assessed without more information.

Fukushima-Daiichi-2

1. This reactor is located between the number 1 and number 2 reactors and it is reported (16:00 on 13th March) that sea water is also being pumped into the core here which means that this reactor will never be used again.. This reactor appears to be identical with reactor 3 , but it is not clear whether MOX fuel is being used. This reactor will be 38 years old later this year.

Fukushima-Daiichi 4,5 and 6

These reactors were under going routine maintenance and refuelling at the time of the earthquake and are thus unaffected.

Fukushima –Daini 1,2,3 & 4

1. The situation at the site is confused with several corrections to statements being made. The latest information suggested that all four units 1 - 4 shut down automatically and that unit 3 is now in a safe cold shutdown state, whereas units 1,2, and 4 are still grid connected.
2. There are reports of a worker being killed and possibly some injured, but this appears to be associated with a normal industrial accident associated with the operation of a crane. One comment I saw suggested that that the operator fell while mounting the crane at the time the earthquake hit and in which case is total unrelated to the operation of the power plant.

Onagawa 1, 2, & 3

1. There are reports of slightly increased radiation levels around one of these reactors, but IAEA state (13:35 on 13th March) that all reactors are under control. Onagawa No 3 reactor is only 10 years old this year

Clearly the overall situation is changing rapidly as more information is becoming available, but the above update was finished at 17:00 on 13th March. If there are any further developments a further update will be written.
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10. Updates: 15th March 2011

10.1 General coverage

The situation has indeed been very fast moving, and one must commend the Japanese authorities on the frequent updates in what must be a difficult situation. However, confusion still rains in the media, and there has been perhaps an over concentration on the nuclear issues when equally important issues have received little or no attention. I originally missed the images of the fires and explosions ranging out of control at the petro-chemical works/ oil refineries show on Friday evening. Apart from these initial pictures there has been limited reference.

The explosions and fires were clearly on a much larger scale than the nuclear explosions and quite probably there were workers killed or injured as the incident occurred during the working day. However, unlike the nuclear incident we are hearing next to no information. One BBC report did say that standing 2-3 miles away from one such plant that the smoke was acrid suggesting at least some toxic chemicals some may well have been carcinogenic. Is it that the fixation on the nuclear issues, serious as they may be, may be diverting attention away from a more serious issue to health? Remember one can readily detect radiation and radioactive contamination at very very low level, far more easily than concentration of chemicals which could be hazardous to health.

10.2 Update on impact on UK gas supplies

[See section 8 above].

According to Reuters, and as predicted wholesale LNG gas prices to the UK had risen 10% by 19:00 this evening [15th March] since the earthquake last Friday. This combined with the situation in the Middle East will see a further upward rise in retail prices as 25%+ of the UK gas supply now comes from LNG.

10.3 Distorted Information in the media.

There will be an urgent review of plans for new nuclear plants, but a review of the safety issues on existing plant needs to be assessed. In many respects the Fukushima plants behaved very well to the earthquake despite their near 40 years of age, but it was the tsunami which I speculated might be the fundamental issue does seen to have been the main cause. I understand that the coastal units at Fukushima-Daiichi were designed to withstand a 6.5m tsunami, which as we now know was significantly overtopped at 9 – 10m – however, more about that later.

There are arguments against nuclear power which can be expounded and a reasoned and rational debate is required as we decide whether or not nuclear power should form part of a future electricity generating mix. However, many statements in last few days on blogs demonstrate a complete naiivity on the part of the writers. In some cases such articles are published in the media, and it is surprising that such comment are published without at least questioning the facts and reasoning behind the statements.

Thus on page 6 of the ***Opinion and Debate Section in the Independent Newspaper today (15th March),*** Terry Duncan writes:

> "I recall in my youth, more than 60 years ago, the hydro-power stations being built all over my native Highlands – they are still operating today.
>
> Why can this proved system of generating electricity not be used nationwide.?
>
> In some areas water to turn the turbines could be pumped and returned to the sea. Modern non corrosive materials could be used for the pumps and pipes making maintenance reasonably trouble free.

The we would have no fears of nuclear accidents, at dated plants, in a country which does experience earthquakes, although at present ‚infrequent"

Terry Duncan demonstrates his ignorance, by

a) Not considering the accidents occurring in earthquakes from dam failures - e.g. the Malpasset Dam near Frejus burst in 1959 killing over 500 people immediately.

b) Where does he expect the power to come from to pump the water. We already have pumped storage schemes to provide a limited amount of storage capacity, but as everyone knows only around 80% of energy is recovered later in generation so it consumes far more energy than it comes.

   Where does Mr Duncan believe the power will come from? What is the point of pumping water around wasting energy unnecessarily when we should be saving it?.

There have been issues reported at three different complexes see section 9.5 above. The current situation (23:00 on 15th March) appears as

10.4 Situation at Onagawa and Fulushima-Daini

10.4.1 Onagawa 1, 2 & 3

All units at this site shut down correctly and went into automatic cooling and are now sufficiently cool that sufficient of the heat arising in the initial hours after shut down had dissipated (see section 5 for a description of the decay heat cooling requirements). It would appear that the decay heat has now fallen sufficiently so to be no longer an issue. Increased radiation levels were detected at this plant, but evidence now suggests that this is arose from the contamination cloud from Fukushima-Daiichi 1 explosion on Saturday morning. Radiation levels at the plant now appear to have fallen significantly..

10.4.2 Fukushima-Daini 1,2,3 & 4

It appears that these four reactors responded differently.

Reactor 3 went through the planned cooling phase as was sufficiently cool 34 hours after the incident.

The immediate first stage emergency core cooling systems failed on all three units causing temperatures within the core to rise with the possibility that a pressure release into the outer containment might have been necessary. However, back up secondary systems were brought into play at ***units 1 and 2*** with the reactors reaching cool condition at 01:24 and 03:52 on 14th March respectively. There had been some concern that water in the suppression pool in unit 1 had risen high, but that has now subsided.

Reactor 4 was still heating on the morning of 14th March and an exclusion zone of 10 km was placed around the plant. Subsequently at 15:42 cooling began and by the evening of 15th the reactor was now cool.

TEPCO and the Government did say (on 14th March) that as soon as the last reactor was cool the exclusion zone would be lifted. However, it is unlikely that this has been as Daini is south of Daiichi and the exclusion zone partly overlaps with the exclusion zone around the Fukushima Daiichi complex.

10.4.3 Fukushima Daiichi

This is the complex with the most serious incidents. There are 6 reactors: units 4, 5, and 6 were not operating at the time of the earthquake but were under refuelling and/or maintenance. All other reactors went through initial shutdown correctly as explained in section 5.

Daiichi Unit 4

A fire broke out in unit 4 cooling pond for spent fuel elements. This was not in the reactor building, but in the holding area where, as a result of the refuelling then under way may have included a significant inventory of the reactor fuel – some of which would be held in the pond before shipping for reprocessing or disposal. However, as noted later, the fire was NOT in the cooling pond.

This cooling pond is like a very deep swimming pool typically 10m or more in depth. The spent fuel is stored at the bottom and there is sufficient depth of water (5m or more) which acts as the biological screen for radiation so above the pool radiation levels are at a safe level. What is a worry was the report in the media of a fire in the pool which would suggest that some of the water had evaporated. That is odd as the volume of water is so large that it would take probably weeks to get to a really serious state. However, if that were to happen then this potentially could be much more serious than the incidents in 1, 2 and 3. If it became dry, then any burst fuel cans could release significant quantities of radio active nuclides. Some of these, Xenon etc have very short half lives and in matters of hours they have decayed to stable isotopes.

Iodine is more problematic as it has a half life of around 9 days, but by 90 days it will have decayed to 1/1000th of the original concentration, by 6 months to less than 1 millionth and in a year 1 trillionth. Supplying people in the immediate vicinity with non radioactive iodine minimises the take up of radioactive iodine in the thyroid gland, and can thus be managed. What is of more concern are releases of radioactive nucleides with half lives of a few years such as Strontium and Caesium an decay very little over the lifespan of a human.

Any radioactive nucleides with long half lives of hundreds or thousands of years are a little consequence radiologically as the radiation levels are low, often very low anyway. There is a myth that the most hazardous radioactive nucleides are those with long half lives. It is those with medium long half lives which we should be most concerned about. Those intense one with short half lives such as iodine can be managed.

The fire occurred ***NOT*** in the cooling pond but as a result of an oil leak in one of the circulating pumps for the cooling water.

For more information on the Daiichi cooling ponds see

http://resources.nei.org/documents/japan/Used_Fuel_Pools_Key_Facts.pdf

Daiichi 5 and 6

Like Daiichi 4, these reactors were not operating and were already shut down before the earthquake hit. There are reports of temperature rises in the cooling ponds for the spent rods, and this might imply a failure of the circulating pumps for the cooling ponds. Through radioactive decay, heat is still emitted from spent fuel for several months, albeit at increasingly lower rates as time progresses. The cooling pumps circulate the water in the cooling ponds in a closed loop through chillers to remove any heat.

It is not known whether in the Japanese cooling ponds the water is also circulated through clinoptilolite a material which absorbs any radioactive particles which might migrate to the cooling pond water from a burst fuel can.

Daiichi 1

A small explosion in the reactor building, but not the containment took place on the morning of the 12th March as noted in section 7. The fact that radiation levels around this reactor have fallen does support the diagnosis that the containment structure is largely intact. Sea water continues to be pumped in to maintain cooling although there are reports that the tops of some of the fuel elements may have been exposed. This would allow the zircaloy cladding of the fuel elements which is designed to retain the radioactive daughter products to become defective and release products. Equally, any steam in contact with hot zircaloy will partly split to hydrogen and oxygen which after pressure release to the outer containment building would bet he source of a potential hydrogen explosion as did happen and this would take any volatile radioactive daughter products away as indeed happened. Please read the commentary about the cooling ponds at Daiichi 4 to understand the consequences of such a release.

As long as such cooling continues the reactor should be brought to a stable condition. The core is almost certainly damaged, but the containment is still intact.

Information indicates that the reactor was due to close at the end of this month after 40 years of operation confirming my speculation in section , so the fact that sea water will have damage the core is of little consequence except that it will make the decommissioning more difficult.

The used of borated water (boric acid) is often mentioned. This is used in PWR and BWR's as a means of control as borated water strongly absorbs neutrons and will ensure that no further chain reactions take place.

Cooling of the core and containment vessel is continuing

Daiichi – 3

An explosion similar to Daiichi 1 took place in the reactor 3 containment building at 11:01 local time yesterday (14th March). This was larger than that of unit 1 but once again the main containment of the core is largely intact although there may be some damage, and the sequence of events leading up to this was similar to that for unit 1. The was evidence of over-pressure within the containment structure but this fell. There was a short surge in radiation to around 50 microSieverts per hour for a relatively short time falling quickly to 10 – 20 microSieverts per hour and in 90 minutes to 4 microSieverts per hour. 10 km distant at the Daini plant – no change in radiation was detected indication there was no contamination reaching the Daini site.

However, another source put the instantaneous radiation at 3000 microSieverts falling to around 200 microSieverts by 12:30. It is probable that this discrepancy comes from different locations of measurement and some may refer to other buildings on the site.

To put this in context the maximum does received by anyone at the Three Mile Island incident in 1979 according to Wikipaedia was 1000 microSieverts (1 milliSievert) with the average for people living within 16 km (80 microSieverts). 1 microSievert is the does one can expect from eating 10 bananas, whereas an Xray could subject the patient to up to 14000 microSieverts. In some places in the world the annual background radiation is as high as 50000 microSieverts per year.

Cooling of the core with seawater continues but it is not clear whether the containment is also being doused with sea water

Daiichi 2

This reactor had an explosion in the early hours of 15th March (JST). This seems to have been more serious and caused damage to the core suppression pool. However, the damage to the external building is less than for units 1 and 3.

As with 1 and 3, core cooling with sea water continues.

10.5 General Comments

Clearly the situation is changing rapidly and apart from this documentation which I started on 12th March other website have appeared who clearly have more time than I do and the reader should also consult these following links. How long I shall continue to update the information does depend on the time I have which is getting more and more limited over next few days. In the meantime: also consult:

- Initial summary 13th March
- Update on 14th March
- further technical information
- Update on 15th March

UPDATES of 17th, 19th and 21st of March follow after this table STATUS of NUCLEAR REACTORS in JAPAN following Earthquake on March 11th 2011.

				Capacity (MWe)		Date	
Name	**Type**	**Status**	**Location**	**Net**	**Gross**	**Connected**	
FUKUSHIMA-DAIICHI-1	BWR	Operational	FUKUSHIMA-KEN	439	460	1970/11/17	Automatic Shutdown
FUKUSHIMA-DAIICHI-2	BWR	Operational	FUKUSHIMA-KEN	760	784	1973/12/24	Automatic Shutdown
FUKUSHIMA-DAIICHI-3	BWR	Operational	FUKUSHIMA-KEN	760	784	1974/10/26	Automatic Shutdown
FUKUSHIMA-DAIICHI-4	BWR	Operational	FUKUSHIMA-KEN	760	784	1978/02/24	Under Maintenance
FUKUSHIMA-DAIICHI-5	BWR	Operational	FUKUSHIMA-KEN	760	784	1977/09/22	Under Maintenance
FUKUSHIMA-DAIICHI-6	BWR	Operational	FUKUSHIMA-KEN	1067	1100	1979/05/04	Under Maintenance
FUKUSHIMA-DAINI-1	BWR	Operational	FUKUSHIMA-KEN	1067	1100	1981/07/31	Automatic Shutdown
FUKUSHIMA-DAINI-2	BWR	Operational	FUKUSHIMA-KEN	1067	1100	1983/06/23	Automatic Shutdown
FUKUSHIMA-DAINI-3	BWR	Operational	FUKUSHIMA-KEN	1067	1100	1984/12/14	Automatic Shutdown
FUKUSHIMA-DAINI-4	BWR	Operational	FUKUSHIMA-KEN	1067	1100	1986/12/17	Automatic Shutdown
HAMAOKA-1	BWR	Permanent Shutdown	SHIZUOKA-PREFECTURE	515	540	1974/08/13	[redacted]
HAMAOKA-2	BWR	Permanent Shutdown	SHIZUOKA-PREFECTURE	806	840	1978/05/04	[redacted]
HAMAOKA-3	BWR	Operational	SHIZUOKA-PREFECTURE	1056	1100	1987/01/20	Under maintenance
HAMAOKA-4	BWR	Operational	SHIZUOKA-PREFECTURE	1092	1137	1993/01/27	Continued operation
HAMAOKA-5	BWR	Operational	SHIZUOKA-PREFECTURE	1212	1267	2004/04/26	Continued operation
HIGASHI DORI 1 (TOHOKU)	BWR	Operational	Aomori Prefecture	1067	1100	2005/03/09	Under maintenance
JPDR	BWR	Permanent Shutdown	IBARAKI	12	13	1963/10/26	[redacted]
KASHIWAZAKI KARIWA-1	BWR	Operational	NIIGATA-KEN	1067	1100	1985/02/13	Continued in operation
KASHIWAZAKI KARIWA-2	BWR	Operational	NIIGATA-KEN	1067	1100	1990/02/08	Not operating at time
KASHIWAZAKI KARIWA-3	BWR	Operational	NIIGATA-KEN	1067	1100	1992/12/08	Not operating at time
KASHIWAZAKI KARIWA-4	BWR	Operational	NIIGATA-KEN	1067	1100	1993/12/21	Not operating at time
KASHIWAZAKI KARIWA-5	BWR	Operational	NIIGATA-KEN	1067	1100	1989/09/12	Continued in operation
KASHIWAZAKI KARIWA-6	BWR	Operational	NIIGATA-KEN	1315	1356	1996/01/29	Continued in operation
KASHIWAZAKI KARIWA-7	BWR	Operational	NIIGATA-KEN	1315	1356	1996/12/17	Continued in operation
OHMA	BWR	Under Construction	AOMORI	1325	1383		[redacted]
ONAGAWA-1	BWR	Operational	MIYAGI PREFECTURE	498	524	1983/11/18	Automatic Shutdown
ONAGAWA-2	BWR	Operational	MIYAGI PREFECTURE	796	825	1994/12/23	Automatic Shutdown
ONAGAWA-3	BWR	Operational	MIYAGI PREFECTURE	796	825	2001/05/30	Automatic Shutdown
SHIKA-1	BWR	Operational	ISHIKAWA-KEN	505	540	1993/01/12	Tripped on 1st March 2011 had not been restarted
SHIKA-2	BWR	Operational	ISHIKAWA-KEN	1108	1206	2005/07/04	Was shut down for routine maintenance a few hours before earthquake
SHIMANE-1	BWR	Operational	SHIMANE PREFECTURE	439	460	1973/12/02	Under maintenance
SHIMANE-2	BWR	Operational	SHIMANE PREFECTURE	789	820	1988/07/11	Continued in normal operation
SHIMANE-3	BWR	Under Construction	SHIMANE PREFECTURE	1325	1373	2011/12/15	[redacted]
TOKAI-2	BWR	Operational	IBARAKI-KEN	1060	1100	1978/03/13	Automatic Shutdown

TSURUGA-1	BWR	Operational	FUKUI	340	357	1969/11/16	Under maintenance
MONJU	FBR	Long-term Shutdown	FUKUI	246	280	1995/08/29	[redacted]
TOKAI-1	GCR	Permanent Shutdown	IBARAKI-KEN	137	166	1965/11/10	[redacted]
FUGEN ATR	HWLWR	Permanent Shutdown	FUKUI	148	165	1978/07/29	[redacted]
GENKAI-1	PWR	Operational	SAGA PREFECTURE	529	559	1975/02/14	Continued in normal operation
GENKAI-2	PWR	Operational	SAGA PREFECTURE	529	559	1980/06/03	Under maintenance
GENKAI-3	PWR	Operational	SAGA PREFECTURE	1127	1180	1993/06/15	Under maintenance
GENKAI-4	PWR	Operational	SAGA PREFECTURE	1127	1180	1996/11/12	Continued in normal operation
IKATA-1	PWR	Operational	EHIME PREFECTURE	538	566	1977/02/17	Continued in normal operation
IKATA-2	PWR	Operational	EHIME PREFECTURE	538	566	1981/08/19	Continued in normal operation
IKATA-3	PWR	Operational	EHIME PREFECTURE	846	890	1994/03/29	Continued in normal operation
MIHAMA-1	PWR	Operational	FUKUI	320	340	1970/08/08	Under maintenance
MIHAMA-2	PWR	Operational	FUKUI	470	500	1972/04/21	Continued in normal operation
MIHAMA-3	PWR	Operational	FUKUI	780	826	1976/02/19	Continued in normal operation
OHI-1	PWR	Operational	FUKUI	1120	1175	1977/12/23	Started after maintenance a few hours before earthquake .Continued in normal operation
OHI-2	PWR	Operational	FUKUI	1120	1175	1978/10/11	Continued in normal operation
OHI-3	PWR	Operational	FUKUI	1127	1180	1991/06/07	Continued in normal operation
OHI-4	PWR	Operational	FUKUI	1127	1180	1992/06/19	Continued in normal operation
SENDAI-1	PWR	Operational	KAGOSHIMA PREFECTURE	846	890	1983/09/16	Continued in normal operation
SENDAI-2	PWR	Operational	KAGOSHIMA PREFECTURE	846	890	1985/04/05	Continued in normal operation
TAKAHAMA-1	PWR	Operational	FUKUI	780	826	1974/03/27	Under maintenance
TAKAHAMA-2	PWR	Operational	FUKUI	780	826	1975/01/17	Continued in normal operation
TAKAHAMA-3	PWR	Operational	FUKUI	830	870	1984/05/09	Continued in normal operation
TAKAHAMA-4	PWR	Operational	FUKUI	830	870	1984/11/01	Continued in normal operation
TOMARI-1	PWR	Operational	HOKKAIDO	550	579	1988/12/06	Continued In normal operation
TOMARI-2	PWR	Operational	HOKKAIDO	550	579	1990/08/27	Continued In normal operation
TOMARI-3	PWR	Operational	HOKKAIDO	866	912	2009/03/20	Continued In normal operation
TSURUGA-2	PWR	Operational	FUKUI	1108	1160	1986/06/19	Continued in normal operation

The Incident at the FUKUSHIMA Nuclear PLANT - March 2011

- **Update 10:00 (GMT), 19:00 (JST) on 17th March 2011**
- **An update as of 23:00 (GMT) on 19th March 2011 follows as section 12**
- **A further update as of 23:00 (GMT) on 21st March follows as section 13 (in red)**
- **Summary Tables of situation from the JAIF website are shown in the appendix**

11. Background

This account should be read as a continuation of the accounts written previously on 12th, 13th and 15th March.

The situation continues to be changing. However, more sources of information are becoming available and the attempt here is to be as objective as possible by seeking several sources. However, in several cases information is still limited. Furthermore statements are being made which are likely to cause unnecessary concern and there is question as to the credibility of some statements in the media and concern may be directed in the wrong direction and be counter-productive.

JAIF provide regular (twice daily) summaries of the situation at all Fukushima reactors at both the Daiichi and Daini sites. The latest version of this at 17:00 (JST) on 17th March is attached at the end of this account.

11.1 Nuclear plants in Japan.

Of the 54 reactors in Japan, 40 were either under going maintenance (i.e. shut down) or continued in operation and were thus unaffected by the earthquake. Three further reactors were shut down for refuelling and are on the Fukushima Daiichi site – more about them later. All eleven remaining plant shut down automatically and went through core cooling as expected. The reactor at Tokai and the three at Onagawa and Reactor 3 at Fukshima Daini all achieved normal cool down within 2 days. The remaining reactors i.e. 1,2 & 4 at Fukushima Daini and all reactors at Fukushima Daiichi are covered in separate section below. The JAIF website provides 2 – 3 updates daily on technical state of all reactors including pressure measurements etc.

11.2 Situation at Fukushima_Daini

This site has four 1100 MW Reactors and is located a short distance down the coast from Fukushima Daiichi – the plant which has suffered significant damage

As mentioned on 15th, all four units at that site are in cold shut down. The normal shut down procedures activated after the earthquake with automatic shutdown. Unit 3 continued cooling as normal and achieved the full cool status after 34 hours. Some problems were experienced with the primary emergency cooling systems on units 1,2 and 4. Secondary systems were brought into play and by the end of 15th March, all reactors were in stable shutdown mode. There was evidence of increased radioactivity, but this may well be from contamination for the Daiichi site.

The latest information from JAIF classifies the incident at Daini 1,2 and 4 a level 3 on the scale 1 – 7. Note that this is a logarithmic scale, so the emergency level was 1/10000th of the incident at Chernobyl.

Table 11.1 Details of Fossil Fuel Power Stations still offline according to TEPCO New Release at 10:00 on 17th March

Station	Type	Units	Status following earthquake	Loss of generation
Hirono	Coal and Oil	1 & 2 600 MW oil 3 & 4 1000 MW oil 5 600 MW coal	Units 2 and 4 tripped following earthquake – still offline	1600MW
Hitachinaka	Bitumous Coal	1 x 1000 MW oil	Unit 1 shut down and is still offline	1000MW
Kashima	Oil	1,2,3 &4 600 MW oil 5 & 6 1000 MW oil	Units 2,3,5 &6 shut down and are still offline	3200MW
Ohi	Oil	1 & 2 1050 MW	Unit 2 shut down and is still offline	1000MW
Higashi-Ohgishima	LNG	1 & 2 1000 MW	Unit 1 shut down and is still offline	1000 MW
			Total	7800 MW

11.3 Thermal Fossil Fuel Power Stations

There is very limited data on other power stations, but clearly there is a significant power shortage in Japan. From the TEPCO Website, one of the main power generators the following information, the following information (Table 11.1) is available which with further research allows the extend of the current loss of generation to be assessed. Note: this does not include issues with power plant of other operators.

To put this in perspective the loss of generating capacity from the nuclear reactors which tripped was around 9000 MW which with the loss of power from fossil fuel generators gives around 16700MW . In the UK the current demand varies through the day but reaches around 45000 MW during the day at this time of year.

11.4 Impact on UK

There continues to be uncertainty on LN gas supplies to UK following the Japanese Earthquake. Bloomberg have indicated that at times the spot market for gas is up 20% on last week and 119% up on a year ago as supplies are diverted to Japan. The situation is more critical in that the pipe line from Libya to Italy is not operating and Germany has shut its oldest nuclear reactors following the earthquake. Bloomberg quoting Michael Hsueh, a London-based Deutsche Bank analyst said about the gas situation that ….“The U.K. market is most vulnerable, followed by Belgium, France and Spain,”

At the same time EU (Carbon Dioxide) emission trading permits have risen noticeably in last few days (albeit dropping back slightly this morning). Coal fired power station emit up to 2.5 times as much CO_2 as gas fired stations and thus require more permits to operate. The reasoning here is that if there a situation develops with gas supplies then generators are likely to switch to coal and pay the increased emission charges. In addition as the UK now imports up to 2/3rds of its coal, the price of coal is also likely to rise. All these effects will impact adversely on domestic UK electricity and gas prices.

Japan will undoubtedly see a surge in carbon dioxide emissions because of the substantial switch to fossil fuels. As I write, MPs in Hungary are debating whether to give 10Million tonnes of its credits to help Japan. It would be interesting to see if other countries follow suit as this would put further pressure on energy prices.

.11.5 The Situation at Fukushima Daiichi

The key issues have moved from the reactors themselves to the associated spent fuel ponds which are located close to each reactor. In addition at Fukushima there is a seventh pond which is shared by all reactors. With this development it is important to understand a little about the function of the spent fuel ponds, and also the fuel assemblies etc. These aspects are covered in this section and subsections 11.5.1 and 11.5.2 before returning to the situation in the reactors themselves in section 11.5.3.

Units 4, 5, and 6 were ***not*** operating at the time of the earthquake, and the issues surrounding unit 4 therefore need some explanation as to what was happening. Units 4, 5 and 6 had been undergoing the biannual maintenance which also includes refuelling. Unlike the British design of MAGNOX reactor (a gas cooled reactor), the Canadian (CANDU heavy water reactor), and to a lesser extent the British Advanced Gas Cooled reactor, all of which can at least in part be refuelled on line, Pressurised Water Reactors (PWR) and the type at Daiichi (boiling Water) BWR have to be shut down completely.

In both PWR and BWR during refuelling which typically takes 2 – 3 months, all the fuel from the reactor are transferred to the spent fuel pond which as explained in section 10.4.3 is like a very deep swimming pool ~10m deep. The fuel is stored at the bottom and there is a minimum of 5m of water above the fuel to provide the biological shield.

After maintenance the reactor is refuelled, but many of the fuel rods will be returned to the reactor only those which have been in the reactor for around 4 – 5 years will be held in the spent fuel pond for up to 6 – 24 months before transfer to more permanent storage or reprocessing.

There appears a noticeable difference between the status in units 5 and 6 and unit 4. The former two were further through the refuelling cycle and there was less fuel in the spent fuel pond as it had been returned to the reactor, whereas in unit 4 it would appear that the full fuel inventory is in the pond.

As indicated in the previous report, section 10.4.3, the developing situation may be more critical if reports that the spent fuel pond in unit 4 is at a very high temperature, and some reports say that it is completely dry.

The reason why the water level in pond 4 has become low or possibly non existent is of particular concern. The pond in this design of BWR is placed near the top of the building to make it easier to transfer the fuel to and from the reactor. In most spent fuel ponds they are either at ground level or partially below ground. The volume of water is very large so that even if boiling too place it would take several days to evaporate the water during which time make up water could be provided. What is more likely is either:

1. Being at the top of the building the structural integrity of the pond became compromised during the earthquake leading to leaks.
2. As the water supplies were critical for dealing with reactors 1,2,3 the workforce may have withdrawn some water as an easy option before they decided to use sea water.
3. The explosion at the adjacent reactor 3 may have compromised the integrity of the structure as in (1) above.

Whatever the cause of the low water, radiation levels in the spent fuel pond hall would rise to potentially dangerous levels and impair the ability to restore the water levels by pumping water directly from the edge into the pond. This is quite probable as they are currently attempting to add water to the pond from helicopters (further from the radiation source therefore less hazardous) or from water cannon outside which would receive a significant amount of shielding from radiation from the building itself.

What happens if this spent fuel pond runs dry as at least one account has suggested. Firstly the fuel rods will start to heat up, but as they have been out of the reactor for some time, they would only be emitting a small proportion of what they had been. Nevertheless without cooling the fuel assembly would rise in temperature and would almost certainly rupture the fuel cladding and cause the release of radioactive particles as explained below.

11.5.1 Fuel assemblies for BWRs and PWRs

11.5.2 Reports of a criticality

Last evening (16th March) there were reports on the BBC Website of the possibility of a criticality happening. This is a most improbable likelihood. The fuel in a BWR is at most at 5% enrichment. In natural uranium, Uranium-235 which is the only active part of Uranium is present at only 0.7% with 99.3% being Uranium-238. Some reactors such as the British MAGNOX and the Canadian CANDU reactor use uranium in its natural enrichment, but most reactors require some enrichment.

However at that enrichment it is not possible for the material to sustain a chain reaction (i.e. go critical), as it requires neutrons to initiate the fission (splitting process). This fission will liberate 2 – 3 further neutrons which potentially could cause more fissions, however, these are readily lost outside the fuel or are moving too fast to create another fission,

In all nuclear reactors it is necessary to have a moderator to slow down the "fast" neutrons so that they can initiate a further fission reaction. The different reactor types use different moderators. Thus in the British MAGNOX and AGR designs, the moderator is graphite, in the Canadian CANDU it is heavy water, whereas in PWR and BWRs it is ordinary water. Thus unlike the British design, which has graphite as the moderator and carbon dioxide as the coolant gas, water is used in both BWR and PWRs as both a coolant ***and*** a moderator. If indeed there is a loss of water as there indeed is then the moderator will be lost in this design and this loss would stop any chain reaction from taking place. However, the fuel elements could still overheat as indicated in the previous section.

One might ask what happens in the cooling ponds – surely there is water present and could act as a moderator?. That is true, but the other requirement is for the fuel to be in a very tight geometry otherwise neutrons are lost and once again no chain reaction can take place. The fuel elements in the spent fuel cooling ponds are held in casks for ease of transport. These casks keep the fuel in a very low density thus preventing any chain reaction.

11.5.3 The situation in the reactors which were operating – i.e. 1, 2, and 3

At the time of writing it would appear that in all three reactors the water level in the pressure vessel is below what it should be an around half way up the fuel meaning that the top half will get very hot and the steam rising would react with the hot zirconium to produce hydrogen – the cause of the explosions.

The fuel integrity in all three reactors has been compromised, but the evidence indicates that the outer containment integrity in unit 1 is undamaged although damage is suspected in both units 2 and 3. Damage to the outer buildings – cuboids is severe in units 1, 3 and 4 (the latter because of issues with the spent fuel pond), but only slight in building 2.

Update at 23:00 (GMT) on 19th March 2011

12. Introduction

Developments have been somewhat less over the last few days. Issues are still serious at Fukushima Daiichi although as time goes by, there are signs of improvement.

Elsewhere in Japan, in the power situation it appears from briefings from TEPCO (19th March) that the Ohi power station is now operational again, although 6800 MW of the TEPCO generating capacity is still shut down – see table 12.1

Table 12.1 Details of Fossil Fuel Power Stations still offline according to TEPCO at 09:00 (JST) on 19th March

Station	Type	Units	Status following earthquake	Loss of generation
Hirono	Coal and Oil	1 & 2 600 MW oil 3 & 4 1000 MW oil 5 600 MW coal	Units 2 and 4 tripped following earthquake – still offline	1600MW
Hitachinaka	Bitumous Coal	1 x 1000 MW oil	Unit 1 shut down and is still offline	1000MW
Kashima	Oil	1,2,3 &4 600 MW oil 5 & 6 1000 MW oil	Units 2,3,5 &6 shut down and are still offline	3200MW
Ohi	Oil	1 & 2 1050 MW	Would appear Ohi is now back up running	
Higashi-Ohgishima	LNG	1 & 2 1000 MW	Unit 1 shut down and is still offline	1000 MW
			Total	6850 MW

There are significant amounts of data now available relating to the Fukushima incident. However, a particularly good link is the video presentation prepared by NNK (the Japanese equivalent of the BBC). This has been translated and placed on Youtube and may be accessed by clicking on the image below. It is noteworthy that much of the analysis I did a week ago with limited data does indeed appear to have been largely correct.
In recent days there has been much objective data on the Internet and other objective assessments in addition to numerous misleading sets of information.

Some good objective sites with links to other information include the JAIF Website which may be access by clicking here. This gives data in a concise form and is updated two – three times a day. The TEPCO website also gives updates sometimes as frequently as hourly. This site also gives information on the general power situation in Japan.

12.1 Other information

The WNN website and IAEA Website also give assessments of the situation, but good accounts which I became aware of three days after I started writing are the blogs written by Barry Brookes and I have included some information from his information of 19th March below.

CTRL+Click on Image to access Youtube – it is around 7 – 8 minutes long

12.2 Level of Nuclear Emergency at Fukushima

Several days ago the Nuclear Level Emergency at Fukushima Daiichi was put at level 4. Today (19th) news reports said this has been raised to level 5. This does not necessarily mean that there has been a deterioration, but that probably a more accurate assessment has been possible. This would put it on the same level as Three Mile Island in 1979 and 100 times less than the situation in Chernobyl. However, the Level of severity does vary from reactor to reactor and this information is clearly indicated on the JAIF Website and summarised in Appendix 3 below. It appears that reactors 1, 2, and 3 are now categorised as Level 5 with unit 4 categorised as level 3. However, if the situation deteriorates in the spent fuel ponds in unit 4, this level will almost certainly be increased. Units 5 and 6 are not affected as an incident and thus have not as yet encountered an emergency level, although see the notes below.

As reported on 17th, the Daini plant remains at level 3 from units 1, 2, and 4 with unit 3 which shut down as expected incurring no emergency.

12.3 Situation at Fukushima Daiichi

12.3.1 Units 5 and 6

Neither reactor was in operation at the time of the earthquake as they were undergoing refuelling, and most of the fuel assemblies had bee returned to the reactor – see tale 12.2 and compare the fuel inventory of 5 and 6 with that of unit 4. However, as there was a lack of cooling in the spent fuel pond the temperature started rising slightly and reach around 65°C by Thursday. There was the possibility that if the water level fell through evaporation then a situation similar to unit 4 might occur where if the fuel became exposed, hydrogen might build up and a further explosion might occur. Consequently the decision was taken to drill three 7 cm holes in the roof of each pond to provide vents to allow any hydrogen to escape. At the same time efforts were made to lay a new electricity cable to the site so that grid electricity could be used and provide a more reliable electricity source to ensure the circulating pumps and associated chillers could be restarted. This was achieved at unit 5 at around 05:00 on 19th and in the early evening in unit 6, and the evidence is that the temperature in the cooling ponds is now falling and hopefully should reach normal levels in a day or so.

Table 12.2 shows the situation with the fuel assemblies and as indicated on 17th, the fuel inventory in the ponds of both units is much less than that in unit 4.

Table 12.1 Fuel Assembly inventory in the Reactor and Spent Fuel Pond in each unit

Reactor Unit	Assemblies in Reactor Core	Assemblies in Spent Fuel Pond	Tons of Fuel in Spent Fuel Pond
1	400	292	50
2	548	587	100
3	548	514	90
4	0	1479	250
5	418	946	160
6	634	867	150

12.3.2 Units 1, 2, and 3

At the time of writing (22:00 on 19th) attempts are being made to connect the temporary grid supply to units 1 and 2 and some reports suggest that this has been achieved, but that checks are being done to get the pumps working in these units to allow more reliable pumping of water into the reactor and cooling ponds.

Unit 1, though seriously damaged does seem to be in a reasonably stable state, and things should improve when power is restored. There remains more concern still on units 2 and 3 as the containment structure is likely to be compromised, but the full extent of the damage is not yet known. Unit 3 is next to unit 4 and radiation levels in the vicinity of unit 4 may restrict the speed at which connection to the temporary cable can be achieved as workers will be more restricted in the time they can work on site to limit their radiation doses to safe level.

12.3.4 Unit 4

Despite being shut down, and the reactor not containing any fuel, this unit is perhaps of most concern relating to the spent fuel pond. The reactor itself is undamaged and may indeed have been open at the time of the earthquake. The problem is solely with the spent fuel pond where not only the spent fuel was being stored, but also the full inventory of the reactor during the refuelling operation.

The heat emission from all 1479 assemblies would have been much higher than that in ponds 5 and 6 and the lack of cooling and the suspected leak of the pond has allowed the fuel elements to be exposed. The temperature measurements in the pond ceased on 14th March when they apparently had reaching 84°C and one must assume that the water actually boiled and evaporated.

The loss of water is particularly serious here as the fuel is kept in an open pond and the top 5m of water acts as a biological shield and as that appears not to be there, none of the workforce can enter the area. Water is being pumped from water cannon and unconfirmed reports suggest that 1200 tonnes of water have been pumped in. It must be assumed that at least 50% if not 80% of this has evaporated and that in effect only 250 – 600 tonnes has been effective. This represents only 25 – 60 cubic metres and with water up to 10 metres deep the pond would normally need probably art least 1000 cubic metres and probably much more depending on the size. Consequently it will be some time before sufficient water is in the pond to provide an adequate biological shield and also adequate cooling. Until this is achieved, the situation is serious, but as each hour goes by the situation will get better – remember the decay heat does reduce with time.

12.4 General Concluding Comments

I am unlikely to continue many more updates apart from occasionally. Further more, I have written things chronologically, and it would be appropriate to try to reorder what has been written into a more effective description, particularly now that many of the original uncertainties as to what happened have now, at least in part, been resolved.

SECTION 13 update as of 21st March 2011

13 Introduction and Summary

In the past 48 hours there has been much less development, however the following are key happenings:

1). A power cable has now been laid to the power plant so that it can now be grid connected.

2) Checks on the integrity of the electrical equipment are being made before switching over to using this equipment rather than the mobile fire trucks etc.

3) Stable cooling to cooling ponds 5 and 6 has been achieved with substantially lower temperatures in both ponds.

4) large quantities of water continue to be pumped into the cooling ponds.

5) White smoke/steam has been seen rising from reactor buildings and workforce have been temporarily withdrawn during these periods

6) Data of radiation levels on an hourly basis are now available in Tokyo and show a noticeable rise in the middle of today 21st March, However, these levels are still low. This information is reproduced in graphical form as Appendix 5

7) Radioactive iodine and caesium have been detected in food produced in exclusion zone and immediately outside, but radiation levels of radioactive iodine and caesium remain very low in Tokyo. These data are tabulated in Appendix 6.

8) All the Reactors at Fukushima Daiini, Onagawa, and Tokai Daini are now in a safe shutdown situations and have been so for last 4 days

13.1 Fukushima Cooling Ponds 5 & 6

Neither of these reactors or cooling ponds has experienced an explosion. Both reactors were in a shut down state and were being refuelled ta the time (see also section 11.5 and 12.3.1). However, the temperature was rising in these ponds and reached around 65 – 67°C very much above normal. There was a danger that continued evaporation could lead to a hydrogen build up and an explosion. Consequently three small holes were drilled in the roof of both cooling ponds to allow escape of the hydrogen. Over the last two days and with the aid of supplementary pumping, the temperature in both pools has been brought down to values in the range of 25 – 35 °C and are largely in a safe and manageable state, although when the grid electricity is fully connected this will bring the units back to normal.

13.2 Fukushima units 1 – 4

Water continues to be pumped from outside into the building at the rate of several tonnes per hour, although this is interrupted periodically if the crews have to be withdrawn when there is uncertainty over radiation levels. The levels at the plant as monitored are now regularly displayed on the internet. They are high and workers will only be allowed limited time close to the reactor buildings before they are relieved. The imperative is to get the electricity connected to the grid which has now been achieved. Subsequently checks are needed on the equipment and then hopefully full circulation with the inbuilt pumps can be resumed.

For the first time the temperature of the cooling pond 2 was displayed on the JAIF WEBSITE today (21st March 22:00 JST) as being 50°C. That measurement is now possible is an encouraging sign although the reading is still rather high.

The next few days will be important and if power is restored and the level of water in pond 4 can be increased to normal so as to provide an adequate biological shield the situation should become more manageable.

13.3 Radiation Levels in Tokyo

Hourly radiation data has been published on the internet since 15th march and a summary is shown in the graph below. Tokyo measure the radiation in microGrays / hr whereas most radiation is measured in micro Sieverts. For beta, gamma, radiation and X-rays the values are the same in both units. However, when alpha radiation is involved there is a weighting factor of 20. The effective weighting factor depends on the proportions of the different radiations, but might well be as high as a factor of 4.

The graph in Figure 13.1 shows the values in micrograys as actually measured. Noticeable is the rise in the last 24 hours to around 0.15 Grays per hour – if that level were to continue and the weighting factor is indeed 4, then the annual radiation dose if maintained at this elevated level would be equivalent to less than a single CT scan (approx 5800 microSieverts a year) and also equivalent to a person living in Aberdeen taking a few transatlantic flight a year.

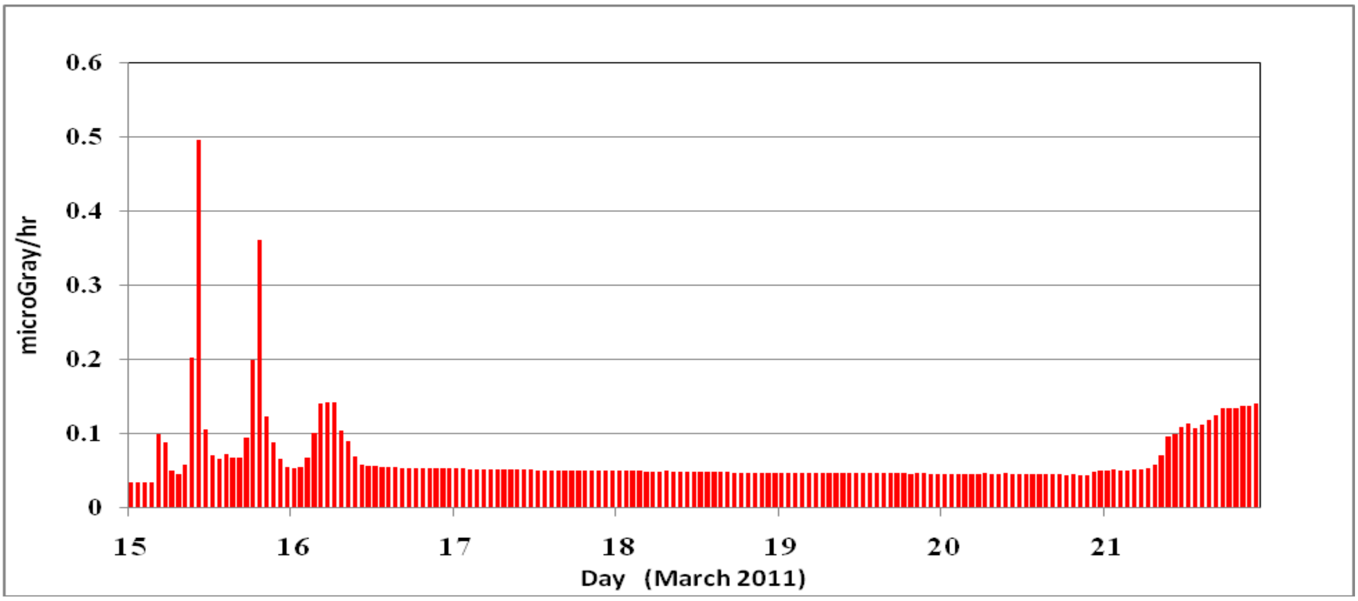

Figure 13.1 Hourly Radiation data measured at Shin-juku in Tokyo.

13.4 Radioactive Particles as measured in Tokyo

Since 15th March the presence of radioactive particles in the air in Tokyo has been measured as shown in Appendix 6.

Note the counting times do vary in the table, but the levels of Iodine 131, 132, and Caesium 134 and 137 are very low having an absolute maximum of 240 Bq/m^2. Remember radioactive potassium-40 naturally occurring within the human body is on a scale of around 4000 Bq (i.e. 4000 disintegrations per second) – Wikipaedia.

Appendices follow on the next pages

Appendix 1 First page of JAIF Assessment on 16th March at 19:00
Appendix 1 First page of JAIF Assessment on 17th March at 16:00
Appendix 1 First page of JAIF Assessment on 19th March at 22:00
Appendix 1 First page of JAIF Assessment on 21st March at 22:00
Appendix 5 Radiation Data as measured at Shin-juku, Tokyo
Appendix 6 Measured concentrations of Iodine 131, 132 abd Caesium 134, 137

APPENDIX 1: The following table is from JAIF at 19:00 on 16th March and should be compared with the similar table at 16:00 on 17th March below

Status of nuclear power plants in Fukushima as of 19:00 March 16 (Estimated by JAIF)

Power Station	Fukushima #1 Nuclear Power Station					
Unit	1	2	3	4	5	6
Electric / Thermal Power output (MW)	460 / 1380	784 / 2381				1100 /3293
Type of Reactor	BWR-3	BWR-4	BWR-4	BWR-4	BWR-4	BWR-5
Operation Status at the earthquake occurred	Service	Service	Service	Outage	Outage	Outage
Core and Fuel Integrity	Damaged	Damaged	Damaged	No fuel rods	Not Damaged	Not Damaged
Containment Integrity	Not Damaged	Damage Suspected	Damage Suspected	Not Damaged	Not Damaged	Not Damaged
Core cooling requiring AC power	Not Functional	Not Functional	Not Functional	Not necessary	Not necessary	Not necessary
Core cooling not requiring AC power	Not Functional	Not Functional	Not Functional	Not necessary	Not necessary	Not necessary
Building Integrity	Severely Damaged	Slightly Damaged	Severely Damaged	Severely Damaged	Not Damaged	Not Damaged
water level of the pressure vessel	Around half of the Fuel	Recovering after Dried-up	Around half of the Fuel	Safe	Safe	Safe
pressure of the pressure vessel	Stable	Fluctuating	Stable	Safe	Safe	Safe
Containment pressure	Stable	D/W: Unknown, S/P: Atmosphere	Stable	Safe	Safe	Safe
Water injection to core (Accident Management)	Continuing (Seawater)	Continuing(Seawater)	Continuing(Seawater)	Not necessary	Not necessary	Not necessary
Water injection to Containment Vessel (AM)	Continuing(Seawater)	to be decided(Seawater)	to be decided(Seawater)	Not necessary	Not necessary	Not necessary
Containment venting (AM)	Continuing(Seawater)	Preparing(Seawater)	Continuing(Seawater)	Not necessary	Not necessary	Not necessary
Fuel Integrity in the spent fuel pool	(No info)	(No info)	Level Low, Preparing Water Injection	Level Low, Preparing Water Injection Damage to Fuel Rods Suspected	Pool Temp. Increasing	Pool Temp. Increasing
Environmental effect	NPS border: 1937 μSv/h at 14:30, Mar. 16					
Evacuation Area	20km from NPS * People who live between 20km to 30km from the Fukushima #1NPS are to stay indoors.					
Remarks	A fire broke on the 4th floor of the Unit-4 Reactor Building around 6AM, Mar. 15, and the radiation monitor readings increased outside of the building: 30mSv between Unit-2 and Unit-3, 400mSv beside Unit-3, 100mSv beside Unit-4 at 10:22, Mar. 15. It is estimated that spent fuels stored in the spent fuel pit heated and hydrogen was generated from these fuels, resulting in explosion. TEPCO later announced the fire was been burned out. Another fire was observed at 5:45, Mar. 16, and then disappeared later. Other staff and workers than fifty TEPCO employees who are engaged in water injection operation have been evacuated. White smoke was seen rising from the vicinity of Unit-3 at around 8:30, Mar. 16. TEPCO estimates that failing to cool the SFP has resulted in evaporation of pool water, generating steam.					

Power Station	Fukushima #2 Nuclear Power Station			
Unit	1	2	3	4
Electric / Thermal Power output (MW)	1100 / 3293			
Type of Reactor	BWR-5	BWR-5	BWR-5	BWR-5
Operation Status at the earthquake occurred	Service	Service	Service	Service
Core and Fuel Integrity	Not Damaged	Not Damaged	Not Damaged	Not Damaged
Containment Integrity	Not Damaged	Not Damaged	Not Damaged	Not Damaged
Core cooling requiring AC power	Functioning	Functioning	Functioning	Functioning
Core cooling not requiring AC power	Not necessary	Not necessary	Not necessary	Not necessary
Building Integrity	Not Damaged	Not Damaged	Not Damaged	Not Damaged
water level of the pressure vessel	(No info)	(No info)	(No info)	(No info)
pressure of the pressure vessel	(No info)	(No info)	(No info)	(No info)
Containment pressure	(No info)	(No info)	(No info)	(No info)
Water injection to core (Accident Management)	Not necessary	Not necessary	Not necessary	Not necessary
Water injection to Containment Vessel (AM)	Not necessary	Not necessary	Not necessary	Not necessary
Containment venting (AM)	Not necessary	Not necessary	Not necessary	Not necessary
Fuel Integrity in the spent fuel pool	(No Info)	(No Info)	(No Info)	(No Info)
Environmental effect	NPS border: 29.4 μSv/h at 12:00, Mar. 16			
Evacuation Area	10km from NPS			
Remarks	All the units are in cold shutdown.			

[Source]
Governmental Emergency Headquarters: News Release (3/16 7:00), Press conference (3/14 11:45, 16:15, 3/15 8:00, 11:00, 16:25, 3/16 11:15)
NISA: News Release (3/14 7:30), Press conference (3/16 12:00)
TEPCO: Press Release (3/14 16:00, 17:35, 3/15 6:00, 12:00, 16:30, 23:35, 3/16 0:00),
Press Conference (3/14 12:10, 20:00, 3/15 8:00, 8:30, 3/16 early morning)

[Abbreviations]
INES: International Nuclear Event Scale
NISA: Nuclear and Industrial Safety Agency
SFP: spent fuel pool
TEPCO: Tokyo Electric Power Company, Inc.

[Significance judged by JAIF]
green : low
yellow : high
red : severe

APPENDIX 2: The following table is from JAIF at 16:00 on 17th March.

Status of nuclear power plants in Fukushima as of 16:00 March 17 (Estimated by JAIF)

Power Station	Fukushima Daiichi Nuclear Power Station					
Unit	1	2	3	4	5	6
Electric / Thermal Power output (MW)	460 / 1380	784 / 2381				1100 /3293
Type of Reactor	BWR-3	BWR-4	BWR-4	BWR-4	BWR-4	BWR-5
Operation Status at the earthquake occurred	In Service -> Automatic Shutdown			Outage	Outage	Outage
Core and Fuel Integrity	Damaged	Damaged	Damaged	No fuel rods	Not Damaged	Not Damaged
Reactor Pressure Vessel Integrity	Unknown	Unknown	Unknown			
Containment Vessel Integrity	Not Damaged	Damage Suspected	Damage Suspected	Not Damaged	Not Damaged	Not Damaged
Core cooling requiring AC power	Not Functional	Not Functional	Not Functional	Not necessary	Not necessary	Not necessary
Core cooling not requiring AC power	Not Functional	Not Functional	Not Functional	Not necessary	Not necessary	Not necessary
Building Integrity	Severely Damaged	Slightly Damaged	Severely Damaged	Severely Damaged	Not Damaged	Not Damaged
Water Level of the Rector Pressure Vessel	Around half of the Fuel	Higher than half of the Fuel	Around half of the Fuel	Safe	Safe	Safe
Pressure of the Reactor Pressure Vessel	Stable	Unknown (run out of battery)	Stable	Safe	Safe	Safe
Containment Vessel Pressure	Unknown	D/W: Unknown, S/P: Atmosphere	Stable	Safe	Safe	Safe
Water injection to core (Accident Management)	Continuing (Seawater)	Continuing(Seawater)	Continuing(Seawater)	Not necessary	Not necessary	Not necessary
Water injection to Containment Vessel (AM)	Continuing(Seawater)	to be decided(Seawater)	Continuing(Seawater)	Not necessary	Not necessary	Not necessary
Containment venting (AM)	Continuing	Preparing	Continuing	Not necessary	Not necessary	Not necessary
Fuel Integrity in the spent fuel pool	(No info)	(No info)	Level Low, Preparing Water Injection	Level Low, Preparing Water Injection Damage to Fuel Rods Suspected	Pool Temp. Increasing	Pool Temp. Increasing
Environmental effect	NPS border: 646.2 μSv/h at 11:10, Mar. 17					
Evacuation	20km from NPS * People who live between 20km to 30km from the Fukushima #1NPS are to stay indoors.					
Remarks	Immediate threat is damage of the fuels in the fuel pool outside the containment vessel at uni-3 and unit-4. To improve the situation of lack of water in the spent fuel pools at uni-3 and unit-4, the self defense force started operation for filling the pool with water in 09:48 of March 17. This operation is to drop a huge bucket of seawater from a helicopter. In addition, watering from the ground by high pressure pump is to be prepared.					

Power Station	Fukushima Daini Nuclear Power Station			
Unit	1	2	3	4
Electric / Thermal Power output (MW)	1100 / 3293			
Type of Reactor	BWR-5	BWR-5	BWR-5	BWR-5
Operation Status at the earthquake occurred	In Service -> Automatic Shutdown			
Status	All the units are in cold shutdown.			
Remarks	Unit-1, 2, 3 & 4, which were in full operation when the earthquake occurred, all shutdown automatically. External power supply was available after the quake. While injecting water into the reactor pressure vessel using make-up water system, TEPCO recovered the core cooling function and made the unit into cold shutdown state one by one. Latest Monitor Indication: 15.9 μSv/h at 12:00, Mar. 17 at NPS border Evacuation Area: 10km from NPS			

Power Station	Onagawa Nuclear Power Station		
Unit	1	2	3
Operation Status at the earthquake occurred	In Service -> Automatic Shutdown		
Status	All the units are in cold shutdown.		
Remarks	Unit-1, 2 & 3 all shutdown automatically when the earthquake occurred. Unit-2 & 3 were then led into cold shutdown state. Unit-2, which had just started operation after planned outage, got into cold shutdown immediately.		

Power Station	Tokai Daini
Operation Status at the earthquake occurred	In Service -> Automatic Shutdown
Status	In cold shutdown.
Remarks	Tokai Daini NPP, which was in full operation when the earthquake occurred, shutdown automatically. Core cooling function was gotten into service after external power supply was recovered on Mar. 13.

[Significance judged by JAIF]

- (green) : low
- (yellow) : high
- (red) : severe

[Source]

Governmental Emergency Headquarters: News Release (3/17 13:00), Press conference (3/14 11:45, 16:15, 3/15 8:00, 11:00, 16:25, 3/16 11:15, 3/17 11:31)
NISA: News Release (3/14 7:30, 3/16 14:00, 20:08), Press conference (3/16 12:00)
TEPCO: Press Release (3/14 16:00, 17:35, 3/15 6:00, 12:00, 16:30, 23:35, 3/16 0:00, 3/17 11:30, 12:00),
Press Conference (3/14 12:10, 20:00, 3/15 8:00, 8:30, 3/16 early morning)

[Abbreviations]

INES: International Nuclear Event Scale
NISA: Nuclear and Industrial Safety Agency
SFP: spent fuel pool
TEPCO: Tokyo Electric Power Company, Inc.

APPENDIX 3: The following table is from JAIF at 22:00 on 19th March.

Status of nuclear power plants in Fukushima as of 22:00 March 19 (Estimated by JAIF)

Power Station	Fukushima Daiichi Nuclear Power Station					
Unit	1	2	3	4	5	6
Electric / Thermal Power output (MW)	460 / 1380	784 / 2381				1100 /3293
Type of Reactor	BWR-3	BWR-4	BWR-4	BWR-4	BWR-4	BWR-5
Operation Status at the earthquake occurred	In Service -> Shutdown	In Service -> Shutdown	In Service -> Shutdown	Outage	Outage	Outage
Core and Fuel Integrity	Damaged	Damaged	Damaged	No fuel rods	Not Damaged	Not Damaged
Reactor Pressure Vessel Integrity	Unknown	Unknown	Unknown			
Containment Vessel Integrity	Not Damaged	Damage Suspected	Might be "Not damaged"	Not Damaged	Not Damaged	Not Damaged
Core cooling requiring AC power	Not Functional	Not Functional	Not Functional	Not necessary	Not necessary	Not necessary
Core cooling not requiring AC power	Not Functional	Not Functional	Not Functional	Not necessary	Not necessary	Not necessary
Building Integrity	Severely Damaged	Slightly Damaged	Severely Damaged	Severely Damaged	Open a vent hole on the rooftop for avoiding hydrogen explosion	
Water Level of the Rector Pressure Vessel	Fuel exposed partially or full	Fuel exposed partially or fully	Fuel exposed partially or fully	Safe	Safe	Safe
Pressure of the Reactor Pressure Vessel	Stable	Unknown	Stable	Safe	Safe	Safe
Containment Vessel Pressure	Unknown	Low	Low	Safe	Safe	Safe
Water injection to core (Accident Management)	Continuing (Seawater)	Continuing(Seawater)	Continuing(Seawater)	Not necessary	Not necessary	Not necessary
Water injection to Containment Vessel (AM)	Continuing(Seawater)	to be decided(Seawater)	Continuing(Seawater)	Not necessary	Not necessary	Not necessary
Containment venting (AM)	Temporally stopped	Temporally stopped	Temporally stopped	Not necessary	Not necessary	Not necessary
Fuel Integrity in the spent fuel pool	Water injection to be considered	(No info)	Water level low, Water Injection continue	Water level low, Preparing Water Injection Hydrogen from the pool exploded	Pool Temp. High, but decreasing	Pool Temp. Increasing
Environmental effect	The West Gate: 313.1 μSv/h at 11:30, Mar. 19 North of Service Building: 2972.0 μSv/h at 19:00, Mar. 19					
Evacuation	20km from NPS ＊People who live between 20km to 30km from the Fukushima #1NPS are to stay indoors.					
INES (estimated by NISA)	Level 5	Level 5	Level 5	Level 3	–	–
Remarks	Immediate threat is damage of the fuels in the fuel pool outside the containment vessel. The operation for filling the pool with water has been conducted since March 17 at Unit-3. Unit-3 is now in operation to fill the water for more than 7 hours from about 14:00 March 19. Unit-4 is now in preparation for filling the water. Attempting to receive external power supply, TEPCO is laying a power cable between the transmission line. The line to Unit-1 and 2 was connected, and External power supply are scheduled tommorrow. Unit 3 to 6 are scheduled to be connected until March 20.					

Power Station	Fukushima Daini Nuclear Power Station			
Unit	1	2	3	4
Electric / Thermal Power output (MW)	1100 / 3293			
Type of Reactor	BWR-5	BWR-5	BWR-5	BWR-5
Operation Status at the earthquake occurred	In Service -> Automatic Shutdown			
Status	All the units are in cold shutdown.			
INES (estimated by NISA)	Level 3	Level 3	–	Level 3
Remarks	Unit-1, 2, 3 & 4, which were in full operation when the earthquake occurred, all shutdown automatically. External power supply was available after the quake. While injecting water into the reactor pressure vessel using make-up water system, TEPCO recovered the core cooling function and made the unit into cold shutdown state one by one. Latest Monitor Indication: 15.9 μSv/h at 12:00, Mar. 17 at NPS border Evacuation Area: 10km from NPS			

Power Station	Onagawa Nuclear Power Station		
Unit	1	2	3
Operation Status at the earthquake occurred	In Service -> Automatic Shutdown		
Status	All the units are in cold shutdown.		
Remarks	Unit-1, 2 & 3 all shutdown automatically when the earthquake occurred. Unit-2 & 3 were then led into cold shutdown state. Unit-2, which had just started operation after planned outage, got into cold shutdown immediately.		

Power Station	Tokai Daini
Operation Status at the earthquake occurred	In Service -> Automatic Shutdown
Status	In cold shutdown.
Remarks	Tokai Daini NPP, which was in full operation when the earthquake occurred, shutdown automatically. Core cooling function was gotten into service after external power supply was recovered on Mar. 13.

[Significance judged by JAIF]
- : low
- : high
- : severe

[Source]
Governmental Emergency Headquarters: News Release (-3/19 17:00), Press conference
NISA: News Release (-3/19 13:30), Press conference
TEPCO: Press Release (-3/19 18:00), Press Conference

[Abbreviations]
INES: International Nuclear Event Scale
NISA: Nuclear and Industrial Safety Agency
SFP: spent fuel pool
TEPCO: Tokyo Electric Power Company, Inc.

APPENDIX 4: The following table is from JAIF at 22:00 on 21st March – consult JAIF WEBSITE for additional information.

Status of nuclear power plants in Fukushima as of 22:00 March 21 (Estimated by JAIF)

Power Station	Fukushima Dai-ichi Nuclear Power Station					
Unit	1	2	3	4	5	6
Electric / Thermal Power output (MW)	460 / 1380	784 / 2381	784 / 2381	784 / 2381	784 / 2381	1100 /3293
Type of Reactor	BWR-3	BWR-4	BWR-4	BWR-4	BWR-4	BWR-5
Operation Status at the earthquake occurred	In Service -> Shutdown	In Service -> Shutdown	In Service -> Shutdown	Outage	Outage	Outage
Core and Fuel Integrity	Damaged	Damaged	Damaged	No fuel rods	Not Damaged	Not Damaged
Reactor Pressure Vessel Integrity	Unknown	Unknown	Unknown	Not Damaged	Not Damaged	Not Damaged
Containment Vessel Integrity	Not Damaged	Damage Suspected	Might be "Not damaged"	Not Damaged	Not Damaged	Not Damaged
Core cooling requiring AC power	Not Functional	Not Functional	Not Functional	Not necessary	Not necessary (AC power available)	Not necessary (AC power Available)
Core cooling not requiring AC power	Not Functional	Not Functional	Not Functional	Not necessary	Not necessary	Not necessary
Building Integrity	Severely Damaged (Hydrogen Explosion)	Slightly Damaged	Severely Damaged (Hydrogen Explosion)	Severely Damaged (Hydrogen Explosion)	Open a vent hole on the rooftop for avoiding hydrogen explosion	
Water Level of the Rector Pressure Vessel	Fuel exposed partially or fully	Fuel exposed partially or fully	Fuel exposed partially or fully	Safe	Safe (in cold shutdown)	Safe (in cold shutdown)
Pressure of the Reactor Pressure Vessel	Stable	Unknown	Unknown	Safe	Safe	Safe
Containment Vessel Pressure	Stable	Stable	Decreasing after increase in Mar., 20th	Safe	Safe	Safe
Water injection to core (Accident Management)	Continuing (Seawater)	Continuing(Seawater)	Continuing(Seawater)	Not necessary	Not necessary	Not necessary
Water injection to Containment Vessel (AM)	Continuing(Seawater)	to be decided(Seawater)	Continuing(Seawater)	Not necessary	Not necessary	Not necessary
Containment venting (AM)	Temporally stopped	Temporally stopped	Temporally stopped	Not necessary	Not necessary	Not necessary
Fuel Integrity in the spent fuel pool	Water injection to be considered	Seawater Injection conducted in Mar. 20th	Water level low, Seawater spray continue and certain effect was confirmed	Water level low, Seawater spray continue Hydrogen from the pool exploded	Pool cooling capability was recovered	Pool cooling capability was recovered
Environmental effect	The West Gate: 269.5 μSv/h at 05:40, Mar. 20 North of Service Building: 2019.0 μSv/h at 15:00, Mar. 21 Radio nuclides were detected in milk produced in Fukushima prefecture and spinach from Ibaragi prefecture.					
Evacuation	20km from NPS ＊People who live between 20km to 30km from the Fukushima Dai-ichi NPS are to stay indoors.					
INES (estimated by NISA)	Level 5	Level 5	Level 5	Level 3	—	—
Remarks	Immediate threat is damage of the fuels in the fuel pool outside the containment vessel. The operation for spraying water to the pool is continuing at Uni-3 and 4 and certain effect has been confirmed based on the declining trend of radiation monitored. Seawater injection to the pool was conducted at Unit-2 on Mar. 20th. Work to recover AC power for Unit-1through 6 is in progress. External AC power has reached to the distribution switchboard for Unit-2. Integrity check of electric equipment of Unit-2 is going on, which must be done before energizing them. External AC power has replaced with the emergency diesel generator in Unit-5. Monitoring results of a few dairy and agricultural products such as milk in Fukushima and spinach in Ibaraki prefectures exceeded the national regulatory standard. Shipment of these products has been restricted for the time being.					

Power Station	Fukushima Dai-ni Nuclear Power Station			
Unit	1	2	3	4
Electric / Thermal Power output (MW)	1100 / 3293			
Type of Reactor	BWR-5	BWR-5	BWR-5	BWR-5
Operation Status at the earthquake occurred	In Service -> Automatic Shutdown			
Status	All the units are in cold shutdown.			
INES (estimated by NISA)	Level 3	Level 3	—	Level 3
Remarks	Unit-1, 2, 3 & 4, which were in full operation when the earthquake occurred, all shutdown automatically. External power supply was available after the quake. While injecting water into the reactor pressure vessel using make-up water system, TEPCO recovered the core cooling function and made the unit into cold shutdown state one by one. Latest Monitor Indication: 13.9 μSv/h at 15:00, Mar. 21 at NPS border Evacuation Area: 10km from NPS			

Power Station	Onagawa Nuclear Power Station		
Unit	1	2	3
Operation Status at the earthquake occurred	In Service -> Automatic Shutdown		
Status	All the units are in cold shutdown.		
Remarks	Safe		

Power Station	Tokai Dai-ni
Operation Status at the earthquake occurred	In Service -> Automatic Shutdown
Status	In cold shutdown.
Remarks	Safe

[Significance judged by JAIF]
- Low (green)
- High (yellow)
- Severe (Need immediate action) (red)

[Source]
Governmental Emergency Headquarters: News Release (-3/21 19:00), Press conference
NISA: News Release (-3/21 15:30), Press conference
TEPCO: Press Release (-3/21 15:00), Press Conference

[Abbreviations]
INES: International Nuclear Event Scale
NISA: Nuclear and Industrial Safety Agency
TEPCO: Tokyo Electric Power Company, Inc.

Appendix 5. Radiation Levels in Tokyo – see also Figure 13.1 (Units microGRays/hr)

	max	min	average	max	min	average	max	min	average	max	min	average
	15th March 2011			**17th March 2011**			**19th March 2011**			**21st March 2011**		
0:00 - 1:00	0.0367	0.0322	0.0345	0.0562	0.0503	0.053	0.0491	0.0436	0.0469	0.0529	0.0478	0.0505
1:00 - 2:00	0.0372	0.0329	0.0347	0.0557	0.0501	0.0526	0.0499	0.044	0.0469	0.0548	0.0475	0.0511
2:00 - 3:00	0.0373	0.0318	0.0345	0.0549	0.05	0.0524	0.0493	0.0449	0.0469	0.0522	0.047	0.0497
3:00 - 4:00	0.0384	0.0319	0.0347	0.0551	0.0499	0.0523	0.0503	0.0444	0.0475	0.0527	0.0474	0.0497
4:00 - 5:00	0.147	0.036	0.1	0.0555	0.049	0.0523	0.0498	0.0447	0.0472	0.0553	0.0485	0.0513
5:00 - 6:00	0.112	0.0562	0.0875	0.0544	0.0497	0.0521	0.0487	0.0438	0.0468	0.0548	0.0493	0.0519
6:00 – 7:00	0.0576	0.0438	0.0495	0.0549	0.0498	0.0519	0.0494	0.0444	0.0472	0.0591	0.0503	0.0537
7:00 – 8:00	0.0507	0.0412	0.0453	0.0539	0.0498	0.052	0.0499	0.0439	0.0475	0.0625	0.0539	0.0585
8:00 – 9:00	0.123	0.0403	0.0573	0.0551	0.0489	0.0516	0.0496	0.0447	0.0473	0.093	0.0588	0.0703
9:00-10:00	0.465	0.122	0.202	0.0538	0.0485	0.0515	0.05	0.0454	0.0476	0.101	0.091	0.0958
10:00-11:00	0.809	0.16	0.496	0.0544	0.0489	0.0514	0.0496	0.0445	0.0473	0.105	0.0944	0.1
11:00-12:00	0.151	0.0781	0.106	0.0532	0.0489	0.0511	0.0491	0.0447	0.047	0.12	0.101	0.109
12:00-13:00	0.0777	0.0663	0.0713	0.0533	0.0486	0.0508	0.0493	0.045	0.0469	0.12	0.106	0.113
13:00-14:00	0.0722	0.0624	0.0658	0.0545	0.0486	0.0507	0.0499	0.045	0.047	0.111	0.104	0.108
14:00-15:00	0.0752	0.0681	0.0716	0.0526	0.0488	0.0506	0.0487	0.0427	0.0465	0.116	0.106	0.112
15:00-16:00	0.0715	0.0646	0.0682	0.0526	0.0488	0.0503	0.0489	0.0433	0.0462	0.126	0.113	0.118
16:00-17:00	0.0749	0.0646	0.0682	0.0523	0.0478	0.0502	0.0493	0.0435	0.0461	0.131	0.12	0.125
17:00-18:00	0.157	0.0669	0.0941	0.0524	0.0475	0.0498	0.0499	0.0443	0.0462	0.139	0.128	0.134
18:00-19:00	0.32	0.113	0.2	0.052	0.0475	0.0501	0.0492	0.0433	0.0463	0.139	0.13	0.135
19:00-20:00	0.458	0.165	0.361	0.0537	0.0472	0.0499	0.0478	0.0445	0.046	0.137	0.131	0.134
20:00-21:00	0.168	0.0955	0.123	0.0523	0.0478	0.0498	0.0483	0.0433	0.0461	0.141	0.131	0.137
21:00-22:00	0.098	0.0761	0.0888	0.0525	0.0473	0.0497	0.0485	0.0443	0.0462	0.14	0.133	0.137
22:00-23:00	0.0763	0.0575	0.0657	0.0525	0.048	0.05	0.0491	0.0426	0.046	0.145	0.136	0.141
23:00-00:00	0.0599	0.053	0.0556	0.0523	0.046	0.0497	0.0488	0.0435	0.0459			
	16th March 2011			**18th March 2011**			**20th March 2011**					
0:00 - 1:00	0.0559	0.0514	0.0538	0.053	0.0474	0.05	0.0487	0.0433	0.046			
1:00 - 2:00	0.0607	0.0506	0.0547	0.052	0.0474	0.0498	0.0492	0.0441	0.0459			
2:00 - 3:00	0.0951	0.0589	0.0672	0.0523	0.0471	0.0493	0.0477	0.044	0.0459			
3:00 - 4:00	0.126	0.0845	0.101	0.0524	0.0464	0.0496	0.0485	0.0435	0.046			
4:00 - 5:00	0.151	0.124	0.141	0.0523	0.0464	0.0489	0.0481	0.0429	0.0457			
5:00 - 6:00	0.16	0.128	0.143	0.0515	0.0468	0.049	0.0485	0.0433	0.0459			
6:00 – 7:00	0.161	0.111	0.142	0.0508	0.0464	0.0489	0.0485	0.0443	0.0461			
7:00 – 8:00	0.11	0.0975	0.104	0.0513	0.0468	0.0493	0.0492	0.0439	0.0458			
8:00 – 9:00	0.103	0.0693	0.0891	0.0518	0.0465	0.0489	0.0489	0.0436	0.0458			
9:00-10:00	0.087	0.0555	0.0688	0.0506	0.0466	0.0486	0.0492	0.0441	0.0462			
10:00-11:00	0.0702	0.0546	0.0582	0.0509	0.0455	0.0483	0.0489	0.0433	0.0457			
11:00-12:00	0.0632	0.0537	0.0565	0.0515	0.0454	0.0485	0.0482	0.0438	0.0459			
12:00-13:00	0.0654	0.053	0.0562	0.0507	0.0466	0.0485	0.0475	0.0433	0.0453			
13:00-14:00	0.0569	0.0529	0.0547	0.0509	0.0464	0.0486	0.0488	0.0419	0.0451			
14:00-15:00	0.0569	0.0513	0.0541	0.0506	0.0457	0.0484	0.0472	0.0421	0.0448			
15:00-16:00	0.057	0.052	0.0542	0.0502	0.0457	0.0481	0.048	0.0423	0.0452			
16:00-17:00	0.0575	0.0517	0.0539	0.05	0.0461	0.0481	0.0472	0.0431	0.0453			
17:00-18:00	0.0572	0.0504	0.0534	0.0496	0.0452	0.0474	0.0484	0.0422	0.0448			
18:00-19:00	0.0562	0.0507	0.0532	0.0499	0.0456	0.0475	0.0473	0.0415	0.0444			
19:00-20:00	0.0565	0.0509	0.0533	0.0491	0.0447	0.0472	0.0468	0.0425	0.0445			
20:00-21:00	0.0555	0.0511	0.0532	0.0498	0.045	0.0473	0.047	0.0414	0.0443			
21:00-22:00	0.0569	0.0506	0.0532	0.0505	0.0445	0.0472	0.0464	0.0416	0.0443			
22:00-23:00	0.0558	0.0508	0.0532	0.0492	0.0443	0.047	0.0524	0.0405	0.0478			
23:00-00:00	0.0553	0.0499	0.0529	0.0492	0.045	0.0471	0.0515	0.0465	0.0494			

Data reconfigured from Shinjuku-ku – click below to access website and latest information it is updated hourly
http://ftp.jaist.ac.jp/pub/emergency/monitoring.tokyo-eiken.go.jp/monitoring/index-e.html

Appendix 6. Iodine 131, 132 and Caesium 134, 137 Bequerels per sqm

Sampling Time	ヨウ素131	ヨウ素132	セシウム134	セシウム137
	15th March			
0:00 -7:12	10.8	8.5	1.9	1.8
7:12- 8:23	3.4	1.2	0.2	0.2
8:23- 9:00	6.2	3.4	0.8	0.8
9:00-10:00	67	59	12	11
10:00-11:00	241	281	64	60
11:00-12:00	83	102	24	23
12:00-13:00	8.7	8.3	2.2	2.2
13:00-14:00	5.6	4.2	0.8	0.8
14:00-15:00	6.2	4.6	1	0.9
15:00-16:00	9.8	7.2	1.9	1.8
16:00-17:00	11	7.5	1.9	1.7
17:00-18:00	11	7.6	1.8	1.7
18:00-19:00	12	9.3	2.4	2.1
19:00-20:00	9.4	6.7	2	2
20:00-21:00	3.3	2.7	0.9	0.7
21:00-22:00	3.4	2.5	0.7	0.6
22:00-23:00	3.4	3	0.9	0.8
23:00-00:00	1.6	1.2	0.3	0.3
	16th March			
0:00 - 1:00	1.3	0.9	0.1	0.2
1:00 - 2:00	1.6	0.6	0.2	0.1
2:00 - 3:00	3.5	2.4	0.6	0.5
3:00 - 4:00	12	7.5	3.1	2.8
4:00 - 5:00	22	15	4.7	4.8
5:00 - 6:00	12	8.9	2.8	2.6
6:00 – 7:00	7.3	5.5	1.7	1.6
7:00 – 8:00	4.6	3.1	0.9	0.9
8:00 – 9:00	2.2	1.6	0.4	0.4
9:00-10:00	1	0.7	0.1	0.2
10:00-11:00	0.6	0.4	0.1	0.1
11:00-12:00	1.2	0.6	0.1	0.1
12:00-13:00	2.6	0.9	0.2	0.2
13:00-14:00	0.9	0.4	0.1	0.1
14:00-15:00	0.4	0.4	0.1	ND
15:00-16:00	0.3	0.3	0.1	ND
16:00-17:00	0.6	0.9	0.2	0.1
17:00-18:00	0.3	0.4	ND	ND
18:00-19:00	0.2	0.3	0.1	0.1
19:00-20:00	0.2	0.4	0.1	ND
20:00-21:00	0.1	0.3	ND	ND
21:00-22:00	0.2	0.4	0.1	ND
22:00-23:00	0.2	0.4	0.1	0.1
23:00-00:00	0.1	0.3	ND	ND

Sampling Time	ヨウ素131	ヨウ素132	セシウム134	セシウム137
	17th March			
0:00 - 1:00	0.1	0.3	ND	ND
1:00 - 2:00	0.2	0.2	ND	ND
2:00 - 3:00	0.1	0.2	ND	ND
3:00 - 4:00	0.1	0.3	ND	ND
4:00 - 5:00	0.1	0.2	ND	ND
5:00 - 6:00	0.1	0.3	ND	ND
6:00 – 7:00	0.1	0.3	ND	ND
7:00 – 8:00	0.1	0.3	0.1	ND
8:00 – 9:00	0.1	0.3	ND	ND
9:00-10:00	0.2	0.2	ND	ND
10:00-11:00	0.2	0.3	ND	ND
11:00-12:00	0.2	0.3	ND	ND
12:00-13:00	0.2	0.2	ND	ND
13:00-14:00	0.2	0.2	ND	ND
14:00-15:00	0.2	0.3	ND	ND
15:00-16:00	0.2	0.3	0.1	ND
16:00-17:00	0.1	0.2	ND	ND
17:00-18:00	0.1	0.2	ND	ND
18:00-19:00	0.1	0.2	ND	ND
19:00-20:00	0.1	0.2	ND	ND
20:00-21:00	0.1	0.2	ND	ND
21:00-22:00	0.1	0.2	ND	ND
22:00-23:00	0.1	0.2	ND	ND
23:00-01:00	0.1	0.1	ND	ND
	18th March			
1:00 - 3:00	0.1	0.1	ND	ND
3:00 - 5:00	0.1	0.1	ND	ND
5:00 - 6:00	0.1	0.2	ND	ND
6:00 – 7:00	0.1	0.2	ND	ND
7:00 – 8:00	0.1	0.2	ND	ND
8:00 – 9:00	0.2	0.4	ND	ND
9:00-10:00	0.1	0.2	ND	ND
10:00-11:00	0.1	0.1	ND	ND
11:00-12:00	0.1	0.2	0.1	ND
12:00-13:00	0.2	0.1	ND	ND
13:00-14:00	0.1	0.1	ND	ND
14:00-15:00	0.1	0.1	ND	ND
15:00-16:00	0.1	0.1	ND	ND
16:00-17:00	0.1	ND	ND	ND
17:00-18:00	0.1	0.1	ND	ND
18:00-19:00	0.1	0.1	ND	ND
19:00-20:00	0.1	ND	ND	ND
20:00-21:00	0.1	0.1	ND	ND
21:00-22:00	0.1	0.1	ND	ND
22:00-23:00	0.1	0.1	ND	ND
23:00-00:00	0.1.	0.1	ND	ND

Sampling Time	ヨウ素131	ヨウ素132	セシウム134	セシウム137
	19th March 2011			
0:00 - 1:00	0.1.	0.1.	ND	ND
1:00 - 2:00	0.1.	0.1.	ND	ND
2:00 - 3:00	0.1.	0.1.	ND	ND
3:00 - 4:00	0.1.	0.1.	ND	ND
4:00 - 5:00	0.1.	ND	ND	ND
5:00 - 6:00	0.1.	0.1.	ND	ND
6:00 – 7:00	0.2	0.1.	ND	ND
7:00 – 8:00	0.3	0.2	ND	ND
8:00 – 9:00	0.3	0.2	ND	ND
9:00-10:00	0.2	0.1	ND	ND
10:00-11:00	0.3	0.1	ND	ND
11:00-12:00	0.1	0.1	ND	ND
12:00-13:00	0.1	0.1	ND	ND
13:00-14:00	0.2	0.1	ND	ND
14:00-15:00	0.1	0.1	ND	ND
15:00-16:00	0.1	0.1	ND	ND
16:00-17:00	0.1	0.1	ND	ND
17:00-18:00	0.1	0.1	ND	ND
18:00-19:00	0.1	0.1	ND	ND
19:00-20:00	0.1	0.1	ND	ND
20:00-21:00	0.2	0.2	ND	ND
21:00-22:00	0.2	0.2	ND	ND
22:00-23:00	0.1	0.1	ND	ND
	20th March 2011			
0:00 - 08:00	0.1	ND	ND	ND
08:00-16:00	0.2	ND	ND	ND
16:00-24:00	1.3	0.3	0.5	0.6
	21st March 2011			
0:00- 3:00	4.4	1.1	2.2	2.2
3:00- 8:00	8.4	2.2	4.4	4.3
08:00-10:00	15.6	3.8	6.8	6.6
10:00-12:00	11.9	3.3	5.8	5.6
12:00-14:00	8.5	2.5	3.2	3.1
14:00-16:00	2.4	1.6	1.7	1.6
16:00-18:00	1.8	2.9	1	0.9
18:00-20:00	2.1	4.3	0.5	0.5
20:00-22:00	2	1.7	0.3	0.3
22:00-24:00	0.9	0.3	0.1	0.1

N.D Not detected

Data reconfigured from Shinjuku-ku – click below to access website and latest information it is updated hourly http://ftp.jaist.ac.jp/pub/emergency/monitoring.tokyo-eiken.go.jp/monitoring/index-e.html