FEW STEPS REMAIN BEFORE A CATASTROPHE: REPORT ABOUT THE FUKUSHIMA DAIICHI NUCLEAR POWER PLANT IN JAPAN

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Dear colleagues, friends and family,

I have been receiving a lot of support (and demand!) from all around the world about those informal emails I regularly send relating to the current nuclear crisis in Japan. I would be joyful if they would not simply reflect the poor quality of information we are receiving about one of the biggest disasters human is partly responsible for (I will go back to the human share of responsibility below). So I decided to extend further more the "mailing list". You are now about 400 people to receive those emails. Feel free to circulate the information, if you find it useful. Sorry for the possible inconvenience to others. Also, sorry to non-English speaking people. For those concerned, feel free to ask me for explanations whether in French or in Spanish, if you need it.

Again, my technical analysis of the current nuclear crisis relies on the information made available by TEPCO and other official authorities, especially the French authority ASN.

main official sources: http://www.tepco.co.jp/en/index-e.html ; http://www.asn.fr/

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1. Update on the current crisis at Fukushima 1

General information:
- The evacuation zone is now 30 km from the nuclear power plant.
- As partial discharges of air containing radioactive materials continue, higher-than-ususal levels of radioactivity have been measured between Fukushima and Tokyo.
- Radioactivity level on site is high and has reached the maximum admissible level for employees. I think that given the situation, the 50 operators on site are clearly sacrificed (although they are "prepared" for this).

Unit 2:
- Partial-meltdown is confirmed. This means that the fuel rods and the core materials are being melting

due to the lack of cooling water. In addition, the reactor vessel itself might be meltdown as well.
- In addition, despite injection of sea-water inside the containment, two successive explosions occurred today and might have damaged a part of the containment structure. This is of major importance. Those explosions certainly correspond to steam explosions (from my understanding) that happen when the hot core meltdown is in contact with the "cold" water. If I understand it right, this would have two major implications: (1) a full meltdown occurred (i.e. the reactor vessel is damaged) since the core materials have been able to reach water outside the vessel; and (2) I know for having calculated the structural behavior of a new design reactor containment under similar conditions that the concrete structure would have been damaged to a point that its integrity can reasonably be questioned, i.e. it probably shows cracks that release radioactive gases continuously outside. This is the most reasonable explanation for the sudden high level of radioactivity measured on site.

Units 1 and 3:
- Partial-meltdown is confirmed. There are significant probabilities that a full-meltdown also occurs on those reactors. If it is the case, the consequences will be even worse. As I mentioned in my previous update, unit 3 is using MOX fuel which would release plutonium. According to a Japanese expert (from the video cited below), consequences of MOX fuel radioactivity "could be up to 2 times" the ones of regular nuclear uranium fuel (other units).
- Sea water cooling procedures are going on, but this does not seem to be an effective way to cool the reactors.

Unit 4:
- The unit was shut down before the earthquake.
- A first fire started on Tuesday (apparently being stopped later in the day) as the stock of used fuel assemblies were out of water (the water level apparently dropped).
- The fire produced radioactive gases. The very problem is that the used fuel assemblies are stored in a pool which is not inside the containment building, so that gases would be directly released in the atmosphere.

Units 5 and 6:
- These units were shut down before the earthquake (same as unit 4).
- The temperature of the used fuel assemblies is rising possibly creating fires as for unit 4.

source: http://www.asn.fr/ (TEPCO press releases cannot be used at the present time, see Section 3)

2. Few steps remain before a catastrophe

Following my understanding of the events, with a full meltdown at unit 2, radioactivity would be continuously released and so for a long period of time. Then, in an attempt to stop these releases, authorities will certainly try to cover it by pouring concrete on the containment. But by doing so, I think that pressure will rise again in the containment, so that other explosions might happen again. High uncertainty here.

The worst situation could come from the other units (4 to 6) that we though they were under full control as being "cold shutdown" before the earthquake. Indeed, if cooling is not maintained or not effective enough, fires at units 4 to 6 would release a huge amount of radioactive materials directly into

the atmosphere (storage pool not being in a containment). If fire is sustained, those materials would spread just as it has been the case at Chernobyl where the fire has worsened the consequences of the catastrophe. In addition, at Fukushima, there are 3 units in that situation of risk.

Although of low probability, a cascade of explosions could make all 6 reactors of Fukushima 1 releasing their radioactive materials. This is the worst case scenario towards which we are tending to since the beginning of this nuclear crisis. Indeed, for now, there is no evidence of improvement at all, so that this scenario cannot be avoided. In such a case, we cannot evaluate the potential adverse consequences on both humans and on the environment.

The bottom line is that, to avoid such a catastrophe, cooling the cores is the function that must be maintained at all cost. As using sea-water is not effective enough, they are now attempting to use fresh water from ponds poured from helicopters. This seems to be surreal but it is a 'last chance' option and probably the only way to avoid the catastrophe.

I often make mistakes, so I deeply hope that, once again, I am wrong in my analysis of the situation.

3. About the speculation that accompanies the events

The more I investigate the nuclear events in Japan, the even worse I find the situation and there is no indication for me to think that this will improve in the short term (on the contrary, events are escalating in an exponential way, see Section 1). At first sight we may think this is what Japanese officials are thinking – "the more people know about it, the more they will be overly afraid worsening an already critical situation" – which could be a reasonable explanation to the poor quality of information leaking about what the situation at the Fukushima Daiichi nuclear power plant really is. Indeed, to illustrate this lack of information, I noticed some facts that are quite worrisome: (1) TEPCO press releases now almost only give updates of the other Fukushima power plant site (Daini) for which we know that all reactor cores are cold-shutdown (under full-control, unless another adverse event happens such as fires like at units 4 to 6 of Fukushima 1) and they are currently facing rolling blackouts due to the Tohoku-Chihou-Taiheiyo-Oki earthquake; (2) official foreign nuclear authorities that admit not knowing what really happens inside the Fukushima 1 reactors (namely ASN French authorities); (3) alarming headlines from mainstream media articles are published without referring to any reliable source of information to support their talks; (4) the discrepancy between talks and images that circulate, the former relating to the nuclear situation while the latter refers to the tsunami or to a remote view of the Fukushima Daiichi nuclear site. Etc.

But on the other hand, we should understand how difficult the context is in Japan. Authorities are facing multiple crises – the nuclear crisis being "only" one of them – and they have to take a tremendous amount of critical decisions, so that it is true that they may not effectively report all of them.

As far as the nuclear crisis, it should be said that at that time, NO ONE knows exactly what is going on inside the nuclear power plants, not even TEPCO operators. Information they receive from inside the reactor containments and reactor vessels (pressure, temperature, water level, etc.) is very limited. You can easily imagine how impossible it is to install a camera that would stand to such severe conditions of pressure, temperature, and radioactivity as the ones that currently exist inside the reactors, so they

cannot neither never get any visual feedback from what they are trying to control. In fact, operators are now obliged to rely on indirect sources of information in order to have an idea of what's going on (e.g. they found out of a possible crack in the containment structure of unit 2 – in the so-called "torus" – as they were measuring a suddenly high level of radioactivity on site, see Section 1). The number of parameters operators need to know in order to get an understanding of the reactor state is huge. But those feedbacks can be incomplete, contradictory, or even wrong – in a situation where some detectors may not be working well anymore – making even more difficult to understand the situation, and what decisions are to be made.

As you can see, speculation on the nuclear crisis in Japan is not so much that the Japanese authorities hide information than the fact that information simply does not exist there! Nevertheless, one can argue that given the uncertainty about the gravity of the severity of the nuclear crisis, Japanese authorities should now admit publicly that a worst case scenario – such as the one of Chernobyl – is technically possible, and that probabilities for it have risen significantly indeed (see Section 1). Would this information has an adverse effect on the general situation in Japan (if a large population needs to be evacuated), I think that they should better use of the precautionary principle to avoid at all cost a regrettable catastrophe. But for now, I reasonably think that they are taking their responsibilities seriously and that the lack of information we see is more due to the factors explained above than to a voluntary intervention from the Japanese authorities. Japanese authorities is, as the rest of the World, relying on the 50 TEPCO's operators who are on site.

4. About the factors affecting the operators in the control room

In a control room, operators usually do nothing but checking manometers, and other controllers, and then respond to it. Doing so, they follow already established procedures indicating what to check and what to do according to the information they get. Then, they either close the procedure or open a new one. And this process keep doing until all problems are solved. That way, human errors are minimized thanks to the use of procedures. However, in such a scenario of severe accident, several factors may prevent such an operational process from working properly at Fukushima 1.
First, the parameters are fast changing and issues are multiple (and being multiplied by the number of units), obliging operators to rapidly switch from one procedure to another and they can easily accumulate a huge amount of opened procedures to follow at the same time, all this increasing the risk of loosing track of the events and of the final objective. Second, although, operators currently on site are specially trained for such severe scenarios, no one can deny that operators might be over-stressed by the potential adverse consequences following their decisions and actions (such as releasing radioactive gases into the atmosphere) in such a real situation.
One word about what already happened in the past. Both in Three Mile Island (1979) and Chernobyl (1986), human errors were found to be one of the main causes of the accidents – along with design deficiencies and component failures. In the particular case of Chernobyl, it is especially when operators abandoned procedures that they stepped on the path to disaster . However, a lot of lessons have been learned since those accidents occurred, so that the human factor in the Fukushima accident should be kept to a minimum. Nevertheless, the outcomes of the Japanese nuclear crisis will largely depend on those operators – the most important decisions being made by the Japanese authorities. But, there are more and more signs that the situation is close to become "out of control" (see Section 2).

5. About the nuclear energy debate

The accidents at Fukushima nuclear power plant obviously raise concerns in parts of the World about nuclear energy, and whether or not it is an option in the discussion about alternative energy sources. I said "in parts of the World" because when, in Europe, some are taking radical decisions to "ban" nuclear energy from their energy mix, in other countries, the contrary applies. Indeed, in the US, the trend is to "stay course" and reaffirm their willing to build new plants, while, in France, officials say that there is "no way to phase out from nuclear". Beside the fact that such reassuring speeches are clearly unwise while some thousands miles away Japan is facing a still-worsening nuclear crisis, I found in those discussions two remaining arguments advanced about nuclear energy to which it shall be responded.

sources: http://bigbrowser.blog.lemonde.fr/2011/03/15/fukushima-le-debat-sur-le-nucleaire-reactive-en-europe/ ; http://news.businessweek.com/article.asp?documentKey=1376-LI1HCP0D9L3501-4TCREPD29SI7LGV9BD3NC876RR ; http://www.nytimes.com/interactive/world/asia/Japan-Video-Grid.html ; http://fr.news.yahoo.com/68/20110315/tsc-pour-nicolas-sarkozy-pas-question-de-04aaa9b.html

Argument #1: "The accident of Fukushima's nuclear power plant is a particular case"

Nuclear energy is all about controlling an energy source with a very high-density. As part of that control, a lot of components are involved in order to always maintain such a control and to avoid potential incidents or accidents. Those components are designed so that if one fails to work properly, another takes the relay. Redundancy and spatial separation is therefore used as a basis of the plant design to always make sure that the functions are maintained. Some functions are more important for the overall integrity of the plant than others, so that, their design is prioritized in regards to others. For instance, the cooling system is one of the most critical function of a nuclear reactor so that a loss of coolant system is to be avoided at all cost. As there is no "zero risk" with every design, all functions in a plant are based on probabilistic risk assessments, depending on two variables (1) the magnitude (severity) of possible adverse event; and (2) the likelihood (probability) of occurrence of such an event. The overall safety of a nuclear power plant is therefore a trade-off between certain assumptions about the severity and the likelihood of adverse events. By definition, component failures are thus part of the design choices.
Natural disaster are taken into account – to some extend – in plant's design. However, there is always a part of uncertainty when making some assumptions (such as the maximal seismic magnitude that can occur in a certain zone) as they depend on the knowledge available at the time of the design. As a result, there is always a risk that a unpredictable event occurs – i.e. exceeding the design assumptions – which has been the case with the 9.0-magnitude Sendai earthquake and its following tsunami. This has been acknowledged for the current situations in Japan as MIT experts say "*nuclear power plants are designed for earthquakes and hurricanes, and in some places tsunamis. But these were unbelievably large*". This demonstrates that the assumptions taken into account for designing the Fukushima reactors were not conservative enough. Although, new designs might take into account more conservative assumptions, there would always be a risk that these assumptions will be exceeded again. This is actually part of the nuclear reactor design, as being a trade-off between economic and safety criteria.

As far as the "particular case" of the Fukushima accident, an extremely adverse sequence of events is

of low probability. Indeed, the overall average generation II nuclear power plant is about 10^{-5} accident/reactor-year, meaning that there is 1 chance out of 100 000 to face a severe nuclear accident. To evaluate the overall (average) probability related to the operating commercial nuclear reactors, we thus need to multiply this probability by the total number of reactors in operation around the World and the average operating life of one reactor. Roughly, this gives us about 10^{-5} x 440 reactors x 45 years = 0.2 "chance" out of 1 of an accident occurs in a 45 year-period. Although, all reactor accident are not of the same severity, it tells us that the overall probability of accident of one generation is not negligible. Indeed, the current nuclear crisis in Japan shows that the most severe scenarios can happen, and do happen, as unlikely as they are (much lower than 10^{-5} being the OVERALL probability of reactor accident). Therefore, the Fukushima's accident is not a "particular case" but one occurrence of a potential situation. And, as events are independent, there is no reason to say that another severe accident as this one will never happen again, even with a very low probability of occurrence on paper. All this is part of a systemic risk which we cannot avoid with nuclear technology.

source: http://www.technologyreview.com/energy/35100/?nlid=4239&a=f

Argument #2: "New reactor design would stand such natural disasters"

The MIT published an article today saying that "new nuclear power plants may not have failed in Japan." We see here a lot of precaution as we obviously cannot know whether or not another reactor would have sustained such a sequence of events unless a complicated simulation is performed (requiring to know exactly the sequence of events that are still happening at Fukushima). Therefore, comparing one feature to another between different designs is too simplistic as it is the dynamic sequence of events that matters.
In the case of new plants, although new safety features are taken into account in the design, there will always be a certain uncertainty about whether the assumptions will be exceeded or not. In probabilistic terms, the overall probability of accident of generation III+ is of the order of magnitude of 10^{-6}. This means that the overall safety has been increased by a factor of 10 between current operating plants and new plants. However, as shown before, focusing on one plant does not give us the big picture. On that respect, this factor-10 effort would be undermined simply by constructing 10 times more plants as there are today. That way the overall (average) probability of reactor accident would remain the same as today. This represents a major limitation to the viability of a large-scale expansion of nuclear energy as an alternative energy source.

Now, to illustrate the complacent talks towards nuclear energy, let me quote here French President, Nicholas Sarkozy talking about the design of the new AREVA EPR reactor "The idea of the double shell structure is that if a Boeing 747 crashes on the plant, the reactor is not damaged." That's true. The double shell structure of the EPR reactor building would stand such an event and it is part of the new safety features of the FUTURE nuclear EPR reactor. But should I remember that there is no any EPR reactor currently operating in the World. Currently, 5 are under construction while there is about 440 currently operating plants in the world. In that case, this argument is not relevant at all at the time of the nuclear energy crisis in Japan. This kind of official discourses should not be criticized at all cost as they reflect the following political lock-in we face:
"When we act, we create our own reality. And while you're studying that reality . . . we'll act again, creating other new realities, which you can study too, and that's how things will sort out. We're history's actors…and you, all of you, will be left to just study what we do." – attributed to Karl Rove,

former advisor of Georges W. Bush

To conclude on this, I cannot do anything but to urge you, dear reader, not to take as "truthful" the over-reassuring and non-scientifically-based speeches that tend to minimize the seriousness of the situation in Japan or that intend to avoid facing current problems using future prospects. History of humankind is already full of such examples.

sources: http://www.technologyreview.com/energy/35100/?nlid=4239&a=f ; http://fr.news.yahoo.com/68/20110315/tsc-pour-nicolas-sarkozy-pas-question-de-04aaa9b.html ; http://www.nytimes.com/2004/10/17/magazine/17BUSH.html

6. Announcements

Although I respect the fact that some of you may still be convinced that nuclear energy is a desirable option for our energy futures, as a scientist, it is my duty to share with you the systemic problems I found making this technology not a viable large-scale alternative energy source. On that respect, I would appreciate if you would contact me in order to engage such a discussion. I take the challenge of providing to you serious scientific input that assess the nuclear energy is not viable neither on the mid-term nor on the long run. Then, you will be free to make your own (knowledgeable) judgment, hopefully not falling into the trap of the numerous nuclear energy myths.

Last, for those of you who are settled in Barcelona, the ICTA department of the Universitat Autònoma de Barcelona is organizing a public discussion on Monday March 21st related to the Fukushima events. Along with Pep Puig, professor of Energy and Society at the UAB, I will present the sequence of events which occurred at Fukushima nuclear power plants and try to answer questions (as best as I can). Check for details and updates here: http://icta.uab.es/divulgacion/actividades.jsp (to be published shortly)
For all others, a very good and knowledgeable presentation of the first events has been provided by a former Toshiba engineer who was responsible for designing the containment vessel of the same type of some reactors of Fukushima 1 (namely units 3 and 5). Although, he has far more experience that I do, we have both a complementary field of expertise as I studied the structural behavior of a new design reactor containment (not the reactor vessel) under severe conditions after core meltdown (i.e. what is happening now at some Fukushima's reactors, see Section 1). The video has a sentence-to-sentence translation into English. His part begins at 8'05". The video is very interesting 'til the end.
http://www.ustream.tv/recorded/13295291