

Special Panel Event about the HBO “Chernobyl” miniseries

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This transcript of the discussions and debates that took place during the event was corrected and approved by the panelists and by the BNS executive committee.

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Table of contents

OPENING WORDS FROM VINCENT MASSAUT	2
1 IN THE CONTROL ROOM, JUST AFTER THE EXPLOSION	3
2 SCENES OF THE FIREFIGHTERS.	7
3 CLEANING OF THE ROOF, WITH 90 SECONDS OF “HUMAN ROBOTS”.	9
4 THE EVACUATION OF THE POPULATION, AND THE EXECUTION OF THE ANIMALS AND PETS	13
5 THE FINAL TRIAL, AND THE SCIENTIFIC EXPLANATION ABOUT THE ACCIDENT.	14
6 ADDITIONAL INFORMATION PROVIDED BY DINA NOTTE	18

Through the document, we use the abbreviation HBOC to denote the HBO-Chernobyl miniseries.

Opening words from Vincent Massaut

This is a bit peculiar BNS session, and risky, because it is a first for us. Mixing video samples with questions and debates was never attended before, and we hope it will be a success.

It is an important session for us all. Many of us have been questioned by friends, relatives and surroundings about the HBO miniseries. Is that real? Is that representative of reality? What do you think about it? Etc. It is one of the goals and objectives of the BNS to help everybody answering those questions. We have therefore gathered a panel of specialists in the field. Of course, we could form such a panel because let's not forget that Belgium is a renowned country for its nuclear traditions and expertise. We started this in the end of the 1950's.

The aim is to discuss certain phases of the accident as portrayed in the series, from a Scientific and Technical perspective, with the support of five panelists, each specialist in different fields. Our five different panelists will be: Dina Notte (EDF, human factors), Hans Vanmarcke (SCK•CEN, radiation protection), Christian Vandecasteele (FANC, emergency planning), Nicolas Castin (SCK•CEN, materials) and Bart Volbrecht (ENGIE Electrabel, nuclear safety). Our moderator will be Gérald Degreef from Tractebel.

The moderator starts insisting that the goal of the evening is to discuss scientific and technical aspects. Panelists and members of the public are kindly asked to respect this instruction and avoid entering in political considerations.

1 In the control room, just after the explosion

We see some samples from the opening of the first episode.

*You morons blew the emergency tanks. This is an emergency everybody remains calm.
The reactor exploded!
All that matters is to flow water through my reactor core.
There is no core! it exploded. The core exploded.
That is impossible, you are confused. RBMK reactors don't explode. Get him out of here.
What about the fire?
Call the fire brigade.*

This scene has given us some insights about the evolution of the accident, and about some interesting aspects of human factors and how they can affect safety.

Question to Bart Volbrecht: How realistic is the portrayal of the accident response to you (operator and authorities)? How were accidents normally managed during the 1980's? And how should they be managed these days?

This is 1986, more than 30 years ago. Situations have evolved of course. Here we see that something suddenly happens in a control room. There are alarm signals, lights are turned on and blinking. This generates lots of stress. But people are trained.

People here in Belgium have a full week training specifically dedicated to managing stress. This is similar to the training given to airplane pilots or to submarine crews. We simulate all possible scenarios to handle all possible emergency situations. There is a full set of procedures and they should know what to do, step by step, to perform an analysis of the situation, and take the appropriate corrective actions. They should go in depth, and analyze the causes, etc. But in any case, there will always be a lot of stress in the control room.

It strikes Bart that the chief operator Diatlov reacted in a very inappropriate way. Perhaps this exact scene was dramatized for the needs of the show. In Belgium, he would be fired immediately. Even at that time in the 1980's, this behavior was unacceptable. He is the leader, and he has a crew. He is also discarding all the input that he receives. After the statement “the core exploded, there is no core”, instead of claiming “you are in shock”, he should ask further questions to understand what is happening. Secondly, he could not have just walked out of the control room, leaving his crew behind. It's not allowed! He must designate a replacement, with the same qualification as him whenever he leaves the room. He should lead his team, but on HBOC we see him lose completely his leadership.

Nevertheless, waking up the whole management and all officials, calling the fire brigade, thereby starting the emergency plan immediately, was a very good approach by the responsible. The sooner the better.

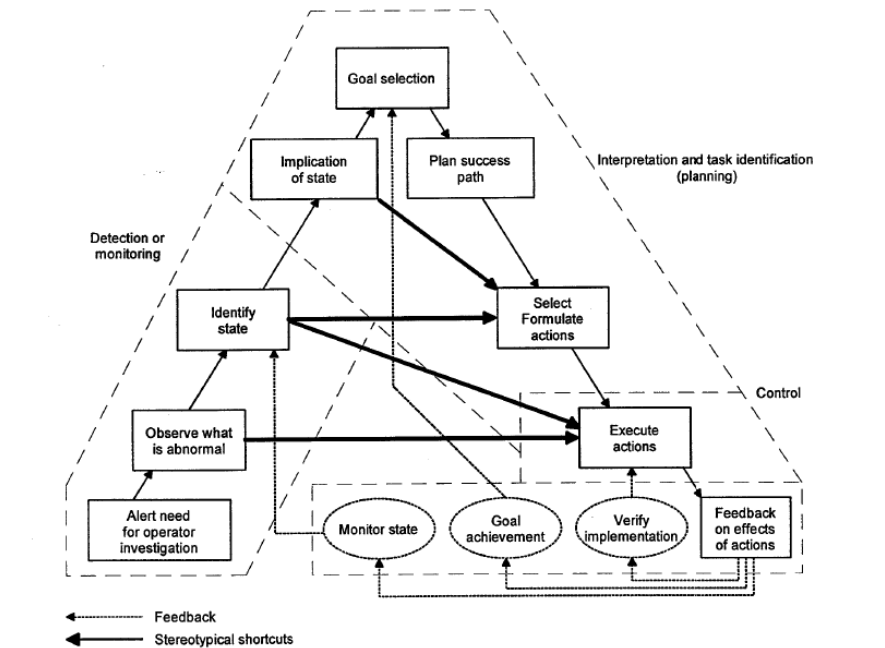
It is important to emphasize that things are managed better nowadays. After the Three-Mile Island accident, and after Chernobyl certainly, in the early 1990's a lot of work was done in the nuclear industry in team building for crews. Here in Belgium, we had a lot of support from US specialists that worked with submarine and airplane crews.

Question to Dina Notte: Is such a reaction normal in emergency conditions?

Concerning Chernobyl, I would say: Yes, it is a normal reaction:

- The dynamic dimension of the accident itself was awfully rapid. The explosions occurred only 41 seconds the automatic shutdown button was pushed! Human beings in stressful situations face cognitive process degradation, and their faculty to make a diagnosis and to take appropriate decisions also degrades, especially under time pressure. In other words: human beings are not computers. We receive information, we treat the information, and then we response to it. This cognitive process was studied by Rasmussen (see figure below for more information). Problem solving is a high cognitive demand in such dramatic accident and with no preparedness it is normal that crew lost its means and the operators remained stunned. In fact, Operators were totally lost, desperate and petrified. That’s normal.
- The overall human cognitive process was so degraded in this stressful situation that the crew had an appropriate mental representation of the reactor state. This is a knowledge-based mistake related on lack of knowledge and experience, which points out the importance of education, training and reliability of procedure.
- As depicted in HBOC, the attitude of the Deputy chief engineer for operations Diatlov, who is aggressive and threatening the staff, was toxic for the crew. Diatlov denying the fact that the reactor has exploded drives panic and horror to its peak. It results in a dramatic effect on operators who are really scared and terrorized as they realize he is not mastering at all the situations.
- We have another illustrative during the control room scene in the last episode; Diatlov violates the basic safety rules commanding to remove completely the control rods. This was bringing more confusion, and panic, on his crew.
- That’s why numerous members of personnel present that night on the plant did suffer from post-traumatic disorder as reported later.

To better understand the cognitive functioning of operators in problem solving situations, here is Rasmussen's double scale. We understand that almost all stages of information processing and action planning have been profoundly altered both at the individual and collective level of the management team.



Question to Nicolas: What do you think of this scene?

We should bear in mind that what we have seen was the opening scene of a Hollywood movie. We should in fact have better watched the control room scene in chapter 5, during the trial, in order to analyze in better details the interactions between protagonists, and what was the role of Diatlov in the chain of events.

Everyone who studies the Chernobyl accident in depth realizes that there remains secrecy about what really happened in this control room. Many pieces of information are not known, and many data have disappeared. Even Russian specialists on nuclear reactors, especially RBMK, are today still debating about the exact causes of the accident. Was it a steam explosion, a hydrogen explosion or a nuclear explosion, is not fully accepted by the community.

From a cinematographic point of view, what the HBOC director wanted to show with the opening scene is that there was a general denial of the situation. Real experts knew that the RBMK reactor could become unstable in some conditions, and even here in Europe we knew it before the accident. But let's keep in mind that the accident occurred during the night shift of operators. These people were not trained properly. They just had a set of instructions to follow, and that's it. They were certainly not trained and prepared in the spirit that was previously described by Bart Volbrecht. They were convinced that this reactor could not explode, because it was fuelled with low-enriched Uranium. That's why Diatlov so lightly deactivated all security systems, etc. He just wanted the test to be completed.

Question to Christian Vandecasteele: At the end of the scene, we see that the fire brigade is called in and that the higher hierarchy should be called. How realistic would this have been for an accident response to a typical turbine hall fire? Wouldn't there have been more information shared beforehand? How is this handled today in Belgium?

If you have a fire in a nuclear installation, you will immediately call the fire brigade. If you have intruders, you will call the police.

But is striking in HBOC is that the firefighters were left on their own. Here in Belgium, local firefighters and local police regularly train in the framework of internal emergency plans, together with the first responders. In case of a real emergency, someone from the nuclear installation will meet them at the entrance and will guide them. Knowing where they are going to, knowing the risks, and being also accompanied with radioprotection experts, telling what protective measures should be taken.

Question from the public: How realistic was the control room scene as described in HBOC? Do we have factual evidence to support that Diatlov really left the control room at some point? Also, I don't understand why we mentioned that the night shift was less competent than the day shift. Since a very special test was ongoing, how can we imagine that a less competent night shift would have undertaken it?

Dina Notte recalled to the audience that the test was not supposed to take place that Saturday night. It was scheduled earlier but postponed because of the need of electrical supply to the nearby cities.

It is very important to mention that most of the workers of the nuclear power plant did not even know that a test was ongoing. What is also amazing is that the day shift willingly switched off many safety systems in preparation of the test. They did not really communicate well about it to the night team, when the shift change was performed. At least in France (where Dina Notte has more than 10 years of working experience), during a shift change, there is a ½h to 1h briefing between the two teams, detailing exactly what is the current status of the reactor, what is to be mentioned, what is unusual, etc. Therefore, we do not say that the people of the night shift were completely incompetent, but they were certainly not prepared for this specific test.

Another important element to consider is that three people within the night shift crew were very young. There were two trainees, and another one was barely 26 years old, with only three months experience. It is truly unbelievable that the test was nevertheless performed in these conditions. This is not serious!

Some remarks from someone in the public:

The number of alarms ringing, and lights flashing, was impressive. I never saw so many at the same time in a movie before. I don't really understand why the operators were not more reactive to those signals. In reality, in Russia and Ukraine, there was no document available in the RBMK control rooms, dealing with procedures, etc. The operators had everything in their minds. They were thus supposed to know everything before they start their duty. This was 30 years ago, in a different philosophy about how to operate nuclear reactors.

2 Scenes of the firefighters.

We see the firefighters arriving on the site and starting to throw water over the wall of the nuclear reactor.

“It tastes metal.”

A fireman gets his hand burned after he touched a piece of graphite. He removes his glove, and we see the hand is completely red.

Later extracts show the pregnant wife of a firefighter, searching for her husband. The nurses don’t want to let her go.

“You can see him 30 minutes. Not a minute more. You can’t touch him, do you understand? You are not pregnant, are you?”

She finally sees her husband. He doesn’t look so bad. But the next extract depicts his later suffering, which seems atrociously painful. He finally looks like a monster, with swollen face, red spots, and bleeding.

Questions to Hans Vanmarcke: Can you tell us about the short-term and long-term effects of irradiation as depicted in HBOC? After a while we see a firefighter collapse due to something that seems a radiation burn from touching the contaminated/activated part. Is such a reaction realistic? What dose rate would be required to have such an effect? And is this compatible with the fact that he doesn’t sustain any other wounds?

One can look through the different UNSCEAR reports on the Chernobyl accident, in particular the one of 1988 on acute radiation effects. When discussing the HBOC series, it is important to realize that a drama series tells stories about people, because the truth, what really happened in Chernobyl, is not narrative and would be in fact very boring to watch. First some information from the UNSCEAR reports:

About 600 workers, mainly reactor personnel and firefighters, who were on site during the night of the accident, were exposed to very high doses of radiation. The main exposures were due to gamma radiation to the whole body and beta radiation to large parts of the skin. Some people also suffered severe thermal burns. One person with severe thermal burns died within the first hour. Another person could not be found because his workstation was located in the collapsed high-activity zone. Acute radiation sickness was diagnosed in 134 workers. 28 of them died from radiation sickness in the first 4 months. Extensive skin lesions caused by beta radiation aggravated the disease in 19 of the 28 deceased patients.

The first patient died after 10 days and 21 of the 28 patients died within the first month after the accident. The higher the radiation dose the faster symptoms occur. For the highest doses vomiting occurred within an hour. In contrast to what is shown in HBOC, people do not collapse from radiation exposure and the skin does not bleed spontaneously in the short term. For example, radiotherapy patients do not feel pain, in spite of receiving doses of several grays. Hands on the graphite caused severe skin injuries from beta radiation and pain within hours. Thermal burns or cuts could have caused the blood and injuries shown in the HBOC series, not radiation exposure.

Acute radiation sickness is extremely painful because the radiation killed so many cells that the body's organs can no longer function properly. Most of the matured cells continue to function, but the stem cells are gone and therefore no, or only few, new cells are formed in the body. The organs fail one after the other, which ultimately leads to death. What you see on HBOC is made to give a cinematographic impression, but it is not reality. The pain is however real. People typically die in 20 to 30 days, in a very painful way.

About the pregnant woman and the risk of losing her baby: the couple, a firefighter and his pregnant wife really existed. As the doses from internal exposure were more than an order of magnitude lower than the doses from external exposure, the radiation emitted by the patients suffering from acute radiation sickness wasn't very high to be harmful to others. The wife of the firefighter lost her baby, but there is no scientific evidence that her unborn child died from radiation exposure.

People with acute radiation sickness are indeed quarantined, but this is for their own protection, not to protect other people. They are placed in quarantine because their immune system is compromised.

Comments from Bart Volbrecht:

As previously pointed out, what we see in HBOC cannot be representative of the reality today. Firefighters on a nuclear site would be guided on the site, accompanied with radioprotection experts, would carry personal dosimeters and would be carefully measured for possible external contamination after the intervention. People nowadays are well trained, and they have clear protocols to follow. These protocols clearly define the absolute upper limit that is tolerated for firefighters, which is 250 mSv in the case of our Belgian nuclear power plants. Firefighters are in fact not familiar with radiation, and radioprotection. So, they naturally ask the question: “If I go to intervene to a nuclear accident, do I risk dying? And if yes, when?” We can thus explain them that they need to receive several Sieverts (Sv) for that, which is much more than the $\frac{1}{4}$ Sv (250 mSv) that they are allowed to receive during the interventions. Their dosimeter triggers an alarm when this limit is nearly exceeded, so they know when to evacuate and to be replaced by other firefighters.

Things were really different in the 1980's, because they didn't have electronic dosimeters with direct readings have we have today.

Comments from Christian Vandecasteele:

Today's firefighters have a full protection, with compressed air bottles on their backs. They should be replaced every 30 minutes because of the autonomy. In the meantime, they will go the control of contamination, where the dosimeter will be read and so the dose received by the people can be controlled gradually.

Question from the public: What was this “taste of metal” that was mentioned a few times in HBOC, but never explained?

Vincent Massaut explained that he heard testimonies from former curators of Chernobyl, also mentioning this “taste of metal”. Dina Notte then explained that it is the sensation after breathing air with a higher concentration of ozone, which was likely formed because of the ionizing radiation from the open reactor.

3 Cleaning of the roof, with 90 seconds of “human robots”.

We watch a sample of the HBOC miniseries:

A soldier is giving instructions to the curators.

“Because of the danger in the surrounding areas you will not work longer than 30 seconds. Listen carefully to each of my instructions. You must do exactly as you have been told. This is for your own safety, and the safety of your comrades. You will enter in reactor building 3, climb the stairs, but do not immediately proceed to the roof. When you get to the top, wait inside, and catch your breath. Leave it for what comes next. You must clean the graphite. Each block weights approximately 40 kilograms. They must be thrown over the edge here.”

“Be careful not to fall in the hole.”

“You will need to move quickly, and you will need to move carefully.”

“These are the most important 90 seconds in your life.”

We then see the curators moving quickly, and throwing block over the edge, under the crackling sound of dosimeters overwhelmed by the ambient radioactivity. A coordinator hits a metal bar to indicate the end of the 90 seconds. One curator falls and struggles to evacuate the roof.

“Thanks soldier. You are done.”

Comments from Christian Vandecasteele:

This scene is realistic. The intervention was prepared, as the curators had a proper briefing and clear and straightforward, although limited to the task to carry instructions: “Just throw some rubbish over the rail, as effectively as possible, during the 90 second of time, after which you go back to safety for decontamination”. Today as well, we would provide all emergency workers (preidentified or not in an emergency response plan or management system) with a just in time briefing describing the actual situation, but also the risk and the most efficient way to intervene with the necessary protective equipment. Those emergency workers preidentified in an emergency response plan or management system should be given, in preparedness, adequate and regularly updated information on the health risks their intervention might involve and on the precautionary measures to be taken in such an event.

In high dose and high risks areas, we make mock-ups, or simulated situations, such as in confined spaces for instance where interventions need to be prepared. Like for examples in the steam generators or working very close to the reactor in a confined space. We repeat the intervention 20 times on the mock-ups before we do it live in the controlled area. Doses can be as high as 1 mSv/h, or even 5 mSv/h. We thus stay well below the dose limits for Belgium.

Very highly skilled and technically precise interventions are sometimes required, like precision welding, mechanical adjustment on a valve, etc. Skilled and trained people are required to perform these tasks. Experience showed some cases where even after having rehearsed the intervention 20

times on the mock-ups, once on the field, the person gets completely stuck. They cannot move forwards or backwards anymore, like the person we saw on HBOC who got his feet stuck in the rubbish. We have seen people being completely stuck in a steam generator, begging: “please, pull me out”. Another phenomenon is that some people completely forget what they had to do! When they go to a relatively confined space with a relatively high dose, they sometimes come back asking what they were supposed to do, even though they repeated it 20 times the previous days.

Of course, in HBOC there is some dramatization, like the crackling sound of the dosimeter. But we should note that in reality, we sometimes put a beeping dosimeter on people, on purpose, because it has a reassuring effect. The person then knows the magnitude of radiation judging from the frequency of the beep. But it can also be counterproductive because they should also focus on their jobs to do, and not anything else.

Christian also shared some interesting comment just before the event, while the panelists were discussing:

- We can never plan everything in advance. Adaptation, and even creativity, will necessarily be needed during any severe accident. As a matter of fact, in case of accident, the most probable is that unforeseen events took place, since the foreseen event were minimized as much as possible.
- The helicopter scene in HBOC, and the need to throw lots of stuff on the top of an open reactor, is hopefully irrelevant for us. This will most certainly never happen, since our reactor cannot explode, and get open air next to a burning fire. They can melt, and then the question is how much of the concrete below they can corrode.

Question to Dina Notte: In regard to the human aspects, how realistic does this scene seem to you? How could they have reduced the stress for this intervention?

To be able to cope with stress, human beings need to be prepared and drilled, which was not the case after the Chernobyl disaster. Here the work to be done on the roof was quite simple and did not require highly skilled people. But let’s remember what the soldier said, as a debriefing: you have to act quickly, BUT you have to be careful... Those two things are completely incompatible.

Soldiers are especially trained to cope with stress, because it cannot be tolerated during military operations. These are professionals, exceedingly well prepared. During operations, everybody knows exactly what they have to do. On the contrary, for what concerns the curators during the cleaning of the roof, the instructions that were given to them were not particularly clear. So, nobody knew precisely what to do.

Another striking element to note is that they apparently had no B nor C plan. For example, what would they have done if someone fell over the roof? I guess that there was no such plan at all. And in general, there was absolutely no emergency plan. Normally actions to be carried out with high risks are well prepared before the intervention by several means:

- Instructions design and validation by experts or by simulation (VR/AR)
- Radiation exposure studies and protection means provided at the workplace and adequate radiation protection for people
- Team working with supervisor and in cross checks for validation of the work to be done

- Appropriate communication means among the team and with maintenance staff in the unit and if needed with the operating team in the CR
- Pre-job briefing and final debriefing with staff when the operations are finished

In HBOC we can observe, in general, and during this sequence in particular, that few attentions has been paid to preparation. Most of the actions after the accident are carried out under improvisation and precipitation.

Comments from Nicolas Castin:

The HBOC miniseries gives the impression to the viewer that curators were forced to go to work, because we see soldiers fetching them under the visual pressure of their guns. Without the intention to discuss politics, we should emphasize that these guns were not necessary in reality. We have to understand the mentality of people back then in the Soviet Union. I think that most of these people were not quite aware of what they were involved in. They were mostly brought there by the soldiers, who they followed willingly because people in the Soviet Union regarded them as authorities from the state, naturally to be obeyed. They most likely received very brief and simple instructions, which they blindly followed without realizing the danger.

Question to Hans Vanmarcke: What can you tell us about the received doses, and the consequences on human health?

During the first years (1986 and 1987), 226,000 liquidators, many of them military servicemen, were involved in the clean-up of the Chernobyl area. The average dose the liquidators received was 170 mSv in 1986 and 139 mSv in 1987. These doses are below the dose limit of 250 mSv for emergency personnel in the Belgian emergency plan and below the thresholds for deterministic effects. If you allow me to make a back of the envelope calculation for the risk of cancer. Based on what we know from epidemiological studies, the exposures in 1986 and 1987 would increase the risk of cancer of the liquidators by about 1%. This is on the top of their baseline risk of cancer of about 30% to 40%.

Note that the average smoker has a risk of lung cancer of about 10%.

Epidemiologic studies were hard to perform after the Chernobyl accident because of the collapse of the Soviet Union, resulting in a worsening of the health care and a decrease in the average life expectancy. Liquidators, many of them military servicemen, came from the whole Soviet Union to work on Chernobyl, and then went back to their families. Their dose reconstruction and medical follow-up are unreliable and incomplete, making it impossible in practice to carry out reliable epidemiological studies.

Question from the public: The dose received by the liquidators you mention, is this a single dose, or is it spread over some time?

The average doses mentioned are for the first years (1986 and 1987) and spread over the time spent in the contaminated areas or in the vicinity of sources, e.g., on the roof. These are of course average doses, and some of the liquidators may have received 250 mSv or more, but still below the thresholds to get deterministic effects. Note that the liquidators experienced a lot of stress, resulting in psychological effects such as post-traumatic stress syndrome and increased suicide and alcoholism.

Question from the public: What about the 50 000 Roentgens per hour that they mention in HBOC? From that, we can calculate that very high doses would be received within only one minute by anyone nearby.

Hans Vanmarcke replies that these are typical additions in movies, because the truth is not narrative to show. He makes an analogy with a film or television series about the landing in Normandy during the Second World War, which is typically visualized by following a few soldiers at the front, while in reality hundreds of thousands of soldiers were fighting in Normandy for several months. With regard to clearing the roof, about 3,000 liquidators were brought in to clean up graphite and other radioactive waste from the reactor roof. The doses received varied with the time and place on the roof, but those in charge ensured that no doses above the thresholds for deterministic effects were received.

Question from the public: Imagine a similar situation in Belgium. Who would be sent to do the work? Engie people? Prisoners?

Bart Volbrecht anticipated the question. There is a couple of possible situations. If you stay within the legal limit, there is no problem. Below 20 mSv per year, things happen normally for any worker of the nuclear industry. But it becomes more difficult if you go above, in emergency or accidental situations. As we already mentioned, there is a general agreement that firefighters can go up to 250 mSv.

Here is the general philosophy applied in Belgium, which is defined in the monitor: in any circumstance, if there is a risk to get a higher dose than 20 mSv, people taking it must be volunteers. Let's insist: a risk that is anticipated, not requiring a direct measurement with personal dosimeters to confirm it. Below that: no excuse, everyone should normally go. The European Union and IAEA recommend that this limit should be between 20 mSv and 100 mSv. Anything above that should be justified by a real need and follow the As Low As Reasonably Achievable (ALARA) principle by favoring rotation of the people if applicable in order to reduce the risks of late effects due to contamination. The new published nuclear emergency plan (01/03/2018) gives 100mSv as the upper value of the range for public and emergency workers in emergency situation, following the international recommendation and EU Directive. The objective of 50mSv is adopted in Belgium as the value not to be exceeded. It is worth noting that these are strict limits in emergency but GUIDELINES.

There are for example life-saving situations. Imagine lifesaving situations, when colleagues are laying on the ground somewhere in the installation, and getting to save them would give you a couple of 100's of mSv, up to 500 mSv or even 1 Sv: what would you do? Only on a voluntary basis.

Then there are more delicate situations, for which we train during emergency exercises. Imagine there is an accident, and an essential valve needs to be open, but it remains blocked. Not opening it would provoke a core melt, causing a release of radioactivity, possibly contaminating the whole province of Antwerpen. But going in means that you will probably take 4-5 Sv, which means deterministic effects, and possible death. At that moment, you need to ask for volunteers. We are not allowed to send people against their will. There was a very good scene in HBOC about the divers, where they asked for volunteers to, precisely, go open some valves. But one must understand that those volunteers need to be very familiar with the installation, because they need to go directly where necessary without wasting time. It is high stress and high risk, so we need operators. In HBOC

they found 3 volunteers. And I am sure that should it ever be necessary, we would also find 2 volunteers within our crews. We exercise this regularly. They need to be briefed about the situation, the medical and radioprotection experts need to inform them about the potential risks, and the potential consequences on their health, or life.

Comment from Hans Vanmarcke:

Of the three most severe nuclear accidents, Three Mile Island, Chernobyl and Fukushima, only doses above the thresholds for deterministic effects were received during the Chernobyl accident, resulting in acute radiation sickness among 134 workers. No one was diagnosed with acute radiation sickness after the Three Mile Island or Fukushima accidents.

4 The evacuation of the population, and the execution of the animals and pets

We saw scenes of HBOC when the local population was evacuated in thousands of busses. Then, we see the scenes when soldiers are visiting the neighborhood, convincing the old people to also evacuate. We also see the execution of the pets that were abandoned, and noticeably when a young soldier does not manage to kill a group of dogs including puppies.

Questions to Christian Vandecasteele: we see people evacuating in calm, obeying to the soldiers. And they have left the animals behind. Is this realistic?

It was probably realistic for what concerns people of the former Soviet Union. They already had a similar evacuation after the Kyshtym disaster in Mayak in 1957. They already experimented the evacuation of several villages in the region.

In Belgium, we have a very high population density, so rapid evacuation is probably not the best option. We might prefer to shelter people during the first days of the hypothetical accident, in order to let enough time to organize a proper evacuation in good conditions. However, we should be prepared for a spontaneous evacuation, even though they would be quite chaotic. Police will play an important role regarding the many people who will try to run away.

Pets and animals are a real problem. Separating families from their pets would be psychologically traumatizing. But our priority remains human beings. I sincerely have no answer. We know there is a problem, but we have no answer. We would already have difficulties to control and decontaminate the people; so taking care of the animals on top of that would be too much.

Comments from Dina Notte:

The evacuation has been truly traumatizing on the population near Chernobyl. Families have been separated. Some have lost a husband, a wife, a brother, a daughter. They never came back. Just imagine the magnitude of the psychological disorder it makes on people's lives. This has also been proven to be the case for the Fukushima accident, where many studies reveal that the trauma was much worse than radioactive contamination.

Comments from Hans Vanmarcke, reacting to the Fukushima anecdote:

Remember the sequence of events. First, there was a magnitude 9 earthquake killing many people and triggering a tsunami flooding 500 km² of Japan's coastline and in which 20,000 people died. Then the earthquake and tsunami caused the nuclear accident in Fukushima. In these difficult circumstances, the evacuation of the surrounding population was not carried out properly by the Japanese. They evacuated the hospitals, but sometimes left the people in buses for several days without proper care, resulting in at least 50 people dying during the evacuation.

Don't forget that there are about 6 million passenger cars in Belgium and that about 90% of the population has access to a car. Evacuation in Belgium is therefore probably spontaneous. I don't want to imagine the traffic jams. Anyway, we would still have to evacuate the hospitals and the elderly.

Question from the public, to Christian Vandecasteele: what happened with the cattle?

The order of magnitude of the contamination in the cattle was 1000's of Bq/kg. The cattle were moved one month later, out of the exclusion zone. They then identified that their milk and meat was heavily contaminated and not anymore consumable, so they slaughtered the animals immediately. In fact, by doing so they created a huge amount of radioactive waste that they could not deal with. That's why we would do differently in Belgium, by finding solutions in negotiation with the farmers. We would for example give hormones to stop the lactation. So, the animal can remain alive longer and we will have more time to better evaluate the need to slaughter them or not.

5 The final trial, and the scientific explanation about the accident.

We watch a sample of HBOC, from the final trial, when Legasov delivers his report.

“You don't need to be a nuclear scientist to understand what happened at the Chernobyl reactor. You only need to know this. There are essentially two things that happen inside a nuclear reactor. The reactivity which generates power either goes up, or it goes down. That's it. All the operators do is to maintain balance.”

We then see Legasov detailing different elements, using red or blue cartels on a board for those that either increase, or decrease the power.

“Uranium fuel creates reactivity, thus increases power.”

“Boron control rods reduce reactivity, like breaks on a car.”

“Water cools the reactor, turning to steam, inducing a positive void reactivity coefficient.”

“We would thus have a vicious circle in our hands, if it wasn't for the negative reactivity coefficient with respect to fuel temperature.”

“This is the beautiful dance taking place, when things are normal.”

“But there is a poison in the reactor, which is Xenon. If you cannot understand how a stalled nuclear reactor can explode, I don't blame you, because you don't work in the control room of a nuclear power plant. But, as it turned out, the man who did, did not understand it either.”

Question to Bart Volbrecht: How do you remember the causes of accident as being communicated within the nuclear sector (IAEA, OECD, UNSCEAR, medias, etc.).

Bart remembers that at the very early stages the communication was fragmented, there was no real technical scenario about what happened because this court session we just saw in HBOC happened nearly a year after the accident. Legasov also came to the IAEA in Vienna, but with a fake report not really telling all the truth. The first real information Bart got was from university colleagues who explained him that those RBMK reactors could indeed have a positive void reactivity coefficient. It was already in German literature from the early 1950's. Not so long after the Second World War, when the nuclear industry was developing, the Germans already wrote that down. Water-graphite combinations could induce positive void reactivity coefficients. Concerning the Chernobyl reactors, we only started to get more precise information, and understand what truly happened, in the 1990's, especially after the Iron curtain collapsed.

Question to Nicolas Castin: How accurate would you judge the information given in the series? How pedagogical is it for the large public? Is it understandable by anyone, thanks to some simplifications?

Nicolas is satisfied that the HBOC miniseries concluded, though without saying it explicitly, that those RBMK reactors should have never been built. Including because these were cheap concepts, for example for not having a real confinement building. But HBOC completely forgot, or willingly omitted to mention a very important piece of information, that RBMK reactors also had a military purpose. One of their qualities was that fuel elements could be moved online, i.e., without stopping the reactor, thereby making breeding of bomb-grade fuel easier.

The scientific explanation given by Legasov is indeed pedagogical, and well thought with the red or blue cartels. The explanation looks realistic, even though they might have got confused in some subtle details, e.g., the void reactivity coefficient was in reality negative in all normal conditions of operations, and it could become positive only far away from them. But it doesn't really matter to explain all that in detail. What matters is that HBOC's viewer understand that a nuclear reactor is indeed complicated, and that there is a neutron balance within conflicting effects (some increase the reactivity, others reduce it) that must be maintained for a stable operation. But unfortunately, HBOC does not make clear that RBMK violated a fundamental philosophy of safety. The fact that the void reactivity coefficient could become positive in some conditions would have strictly prohibited the construction of such a reactor, at least for civil applications. Situations where a shutdown button, the famous AZ-5, becoming the trigger of a bomb should not have even been possible to create.

Nicolas then asked bold questions to the audience. Do we have actual PWR operators in the room? Could you make your reactor explode on purpose, if you wanted to? How many safety systems would you have to deactivate, how long would it take? But is this even possible according to the physics of the reactor? The limited time of the event did not allow to have a long conversation on this topic, but the answer is of course negative, thanks to the intrinsic safe design of the PWR reactors.

Dina Notte reminded the audience that what could happen with PWR reactor, or BWR reactors like Fukushima, is a core melt down because of lack of coolant. But no nuclear explosion.

Nicolas rephrased his question, asking: what about if a terrorist manages to enter in a PWR control room? How easy or how hard would it be to provoke a core melt down on purpose?

Dina then made an interesting comment. Let’s see what happened after 9/11, in the airline industry. Kevlar-armored, bulletproof doors were installed on all airplanes, making it virtually impossible to force one’s way in on flight. This looks to be a positive measure, but then what about the German Wings pilot suicide, killing more than 200 innocent people with him? Thanks to or because of this armored door, the pilot could commit his suicide, crashing the plane, and the other crewmembers could not do anything to stop him. In conclusion, sometimes measures taken against a risk (e.g. terrorist ones) have negative side effects, and it can be difficult to evaluate all risks.

Question from the public: could anyone remind us what was the reason for the test? What were they trying to demonstrate?

It was a commissioning test that had never been performed before up to that stage.

If you have an emergency shutdown, and a loss of onsite power, diesel generators need to start. But they need a certain time to do that. The test concerned the use of the remaining productive capacities of the turbines, which are still rotating thanks to inertia. The idea was thus to use this energy as supply of electricity to feed the safety systems, during the short time period that the diesel generators are getting started.

This is a difficult commissioning test that has been repeatedly delayed and postponed.

Comments from a Russian attendee in the public, concerning RBMK reactors:

I have been in an actual RBMK control room, near Saint Petersburg, which was build and operated before the one at Chernobyl. The control room is still close to its original configuration, except for LSD monitors, which were installed later on. I was surprised by the darkness in the control room depicted in HBOC, which does not seem realistic to me. They did not show that the control room is also filled with plotting devices, that have rolls of papers and pens, to report on data. Also, they did not show that RBMK were followed by computers, continuously calculating the state of the reactor and advising possible dangerous situations. The only problem with those computers is that they were quite slow. They could have helped to avoid the accident, but it didn’t do it on time.

The last comment concerns the military purpose of the RBMK reactors. In the scientific literature, one finds out that they produce 6 kg of Pu, while VVER reactors (these are the Russian equivalent of the PWR reactors) produce 10 kg of Pu. Therefore, when I heard that RBMK had a military purpose, I wonder if it is true, because it seems like using VVER reactors are more efficient in breeding Pu than RBMK.

The whole panel of experts than replied that the key difference between VVER/PWR and RBMK is the possibility to perform online switch of fuel elements. In the first case, these are pressurized reactors. Fuel can thus only be moved during fuel reloading phases, which normally happen once a year or once every 18 months. It is worth noting that France also had graphite-moderated reactors that could be used to produce bomb-grade Pu, and England still have some today. Other CANDU concepts could also be used for it. Several types of reactors across the world are thus potentially suitable for breeding bomb-grade Pu. After about 30 days in the reactor, you have the maximum yield of Pu production, and it is thus the best time to remove the elements and extract it. Removing fuel elements from a pressurized reactor after only 30 days of operations would be highly inefficient from

an economical point of view. That is the reason why graphite-moderated reactors are by far a more efficient option, even if the actual mass of produced Pu per kilogram of U ore is lower.

Comments from another attendee in the public:

The Leningrad RBMK reactor (now Saint-Petersburg) that was mentioned in the previous discussion actually refused to perform the test. It is finally the Chernobyl power plant that was obliged to perform it.

6 Additional information provided by Dina Notte

These thoughts and pieces of information were prepared for a possible discussion during the events but skipped due to time limitation.

We see the chief engineer leaving the control room. He clearly sees graphite debris from the reactor core at the outside of the reactor. Whilst assuming that this is quite dramatized, how realistic is it for people to block out such information? Is there feedback from other events? How can we anticipate such reaction? By training? By interview? By preliminary tests?

To me there are two Human Factor to consider:

- In general, the fact to block out important information is unfortunately a human cognitive characteristic that can be observed in numerous circumstances, even outside the professional life. This blindness can result from environmental conditions (how far was it illuminated at NPP site after the accident due to loss of power), physiological limitations (people could be injured or temporarily lose their vision) or for cognitive process degradation (as it is the case for Diatlov). He was convinced the reactor was intact. This attitude is also called the tunnel effect (“erreur de fixation ou d’ancrage” in French) when people are blocked on a diagnosis for instance and do not explore another hypothesis. They are just stuck. This was the case for TMI, the operators where stuck on the fact the valve was open, but it was not the case, as only the command was considered and not the execution.
- Psychological profile can also explain such blindness as it is again the case of Diatlov. He wanted deeply to succeed the test according to the strategic importance for him to progress in the hierarchy. He formerly worked among a military organization and he has been used to command to men and to be obeyed. Not to be contradicted nor to be questioned. He is uncompromising and inflexible. It is part of his personal profile. To me the only way to avoid such management attitude is to detect these profiles at HR level by psychological tests before personal engagement. If not detectable at that time, management decision should have taken place in order to remove this person from operating team, but we know the situation in Soviet Union was at that time. Blindness is typical from totalitarian regimes. That’s why by fears Akimov and Toptulov will execute the commands of Diatlov.

How is an emergency situation normally managed?

Firstly, accident should be avoided or at least mitigate by a strong design which should be questioned, challenged under scrupulous preliminary safety analysis which should be validated by functional tests and full scope simulator.

It is managed by designing, preparing, organization of defense in depth barriers to face crisis management adding a strong package of training and simulation sessions repetitively along the whole life cycle of a NPP including dismantling. This was not the case in TMI, neither in Chernobyl nor Fukushima. That’s why safety authorities claimed strongly for post-Fukushima actions on crisis management at NPP and at national level, including again design consideration for emergency diesels and the addition of a bunkered crisis building inside the plant integrating a remote shut down control Room at distance for normal control room and shut down station.

First defense in depth relies consequently on safety systems. Second barrier concerns adequate procedure, and third barriers rely on a crisis management organization at plant level, at local level and at National level both on supplier’s and designer headquarters and at political and military level. One should consider the French approach using state approach versus event approach for their accidental and emergency procedure. This has been decided and developed after TMI, because during this accident the operating team was oriented towards an event and were misled by poor instrumentation feedback.

What was really missing to deal the accident and prevent the disaster was the technical support team, which normally should have been called when the power was too low as the third defense in dept. The reports do not precise if this kind of crisis management was foreseen at Chernobyl, but we can make the hypothesis that the immaturity of the safety culture and the authority of Diatlov have played a considerable role.

How can training of personnel allow minimizing human factors in emergency situations?

Training is for sure a key factor of human reliability and is part of the safety culture, especially in the nuclear field. Training can improve:

- Individual competencies and know-how
- Cooperation among the operating team in accident management and its efficiency
- Overall situation awareness and mental model
- Communication skills and leadership among the team
- Recovery of laps and mistakes
- Resilience to stress

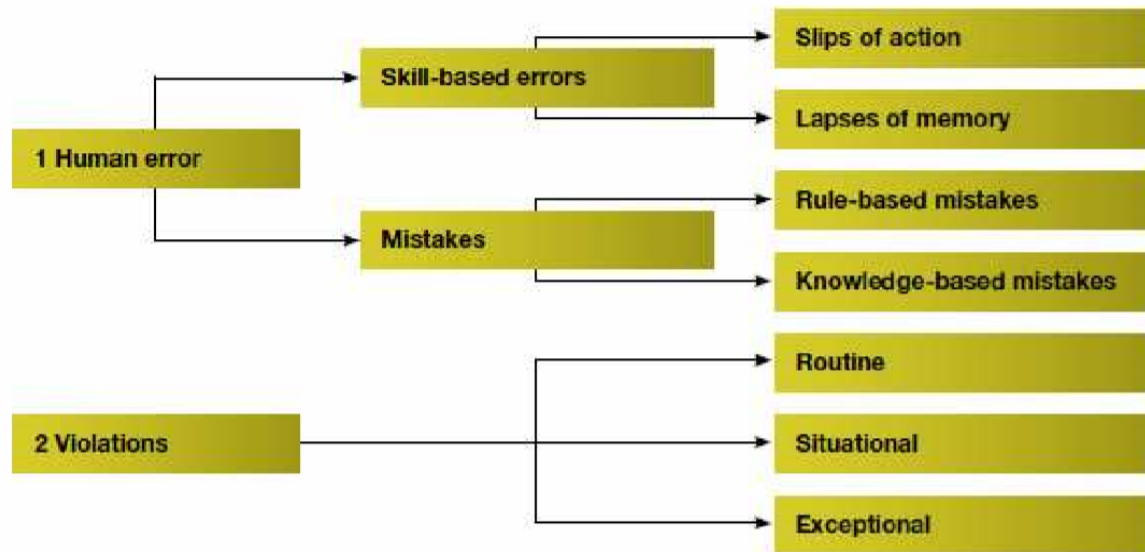
The problem with HOF and training is that crisis scenarios are already known, and we are not prepared nor educated to consider worth scenarios or different scenarios outside those studied by safety engineers or designers or some we have lived (return of experience, simulators). That’s why training methods have their limits.

It is difficult to be prepared to the unexpected!

Training poses also another question for which answers are different from one country to another and from one continent to another. In US operator’s training and license agreement are manage by the WANO which is an external body as Safety Authorities’ bodies. In France, EDF manage itself his fleet of operators which could be contradictory to an independent evaluation system.

Given the fact that the operator is responsible for the accident and the series information that – although not completely correct – the design was flawed. How do you see from an ergonomic perspective the explanation given in the movie?

To better understand my point of view, I invite you to consult the following information on human error. Again, I will not have time to develop these concepts, but I will use them in giving my vision of the accident.



There are two main types of human failure:

- **Human error** is an action or decision which was not intended, which involved a deviation from an accepted standard, and which led to an undesirable outcome.
- **Violations** are intentional failures –deliberate deviation from a rule or procedure.

Human Errors are:

- **Slips** are failures in carrying out the actions of a task. They are described as 'actions-not-as-planned'. Examples would be: picking up the wrong component from a mixed box, operating the wrong switch, transposing digits when copying out numbers and misordering steps in a procedure.
- **Lapses** cause us to forget to carry out an action, to lose our place in a task or even to forget what we had intended to do.
- **Mistakes** are a more complex type of human error where we do the wrong thing believing it to be right. The failure involves our mental processes which control how we plan, assess information, make intentions and judge consequences. Two types of mistakes exist, rule-based and knowledge-based.
 - **Rule-based** mistakes occur when our behavior is based on remembered rules or familiar procedures. We have a strong tendency to use familiar rules or solutions even when these are not the most convenient or efficient.
 - In unfamiliar circumstances we have to revert to consciously making goals, developing plans and procedures. Planning or problem solving needs us to reason from first principles or use analogies. Misdiagnoses and miscalculations can result when we use this **knowledge-based reasoning**

Violations are any deliberate deviations from rules, procedures, instructions and regulations. Violations are divided into three categories: **routine**, **situational** and **exceptional**.

Human are working in a Socio-technical context that presents deviances in the case of Chernobyl

- No propagation and correction of design failures although weaknesses of design were known (weak signals and preparation to resilience). Do not forget the first human error in NPP disaster is a design error.
- Advancement issues for direction staff career resulting in inappropriate decision concerning the test.
- Dominance of production consideration against safety
- Test planned a weekend and postponed

- NPP is running without the full staff and workers including electrical staff because it is the WE
- Absence of crisis management organization & training (preparation)

Human Factors are sensible to internal factors but also to external factors favoring human errors, that’s why we talk about HOF

- Saturday midnight - Sleep deprivation
- Flaw in Shift relief at midnight, it is not recalled that the alarm system and the safety system where shut-off, disconnected. This is human error concerning memory. Still the Shift supervisor of previous team was in the CR and stayed there to follow the test. Field workers are not aware about the test, this should have been explained during the meeting
- The team is composed by young operators and team is disorganized from routine
 - Toptunov is only 26 year and a few months of experience in the CR (end up his scholarship 3 years before). He is unexperimented and he is making the first error that could be recovered if the plant would be shut down (Xenon effect)
 - The 2 young trainees in the control room. They rush out the control room without any mask or protection and will discover the disaster. Coming back to the CR they claim that the explosion has destroyed everything, and the reactor is on fire. Diatlov will continue to ignore the evidence and tell them they are wrong and that’s the reservoir tank that has been destroyed by the explosion
- The team is absolutely not prepared nor trained for this kind of safety test and a chain of human errors could have been recovered somehow but additional violations lead to the disaster with less margin and even no chance anymore at a certain step of degradation to save the situation
- Procedures are Inappropriate.
- The protection means for the operator was not available being in a closed cabinet
- The radiation meters were unusable and not trustful
- The communication means were out of service

Criminal mismanagement: human errors in that domain are the critical ones. Mr. Legasov called that human negligence.

- Akimov and Toptounov who are starting manually the supply pumps will die in vain
- The turbine and the electrical staff prevented the disaster from spreading to the engine room and saved the whole plant sacrifice their lives
- Chief Engineer of the plant send the Deputy Chief Engineer, First Unit Operations, Anatoli Sitnikov to roof of the unit 4 knowing he will not survive
- In the morning, Bagdassarov, Shift Supervisor of Unit 3, will decided alone to shut down the third reactor even if Chief Engineer of the plant told him not to do it.