NHK World, Documentary, (Fukushima), March 5th, 2013 Gordon Taylor 2014-01-13
'Meltdown: Oversights in the Reactor Cooling System' [49:23] http://www.youtube.com/watch?v=ixjlSsUlNBw

(Fukushima Daiichi Nuclear Power Plant. Tokyo Electric Power Company (TEPCO)). (March 5, 2013)
[Narrator].'This is the Fukushima Daiichi Nuclear Power plant, operated by Tokyo Electric Power Company. One of the world's worst nuclear disasters occurred here two years ago.
(Footage of plant).
'The first hydrogen explosion occurred in Reactor 1.
(Reactor 1 building).
[NHK person] 'We filmed this from just ten metres away. It's now nearly 100 microsieverts [per hour]. We've been told not to go closer because of radiation.
[Narrator]. 'Radiation levels are still high. That's made it difficult to investigate the accident. Even now, numerous questions remain. Government officials and experts on Diet panels ended their investigation last year. Efforts to identify the disaster's root causes have slowed since then'.

('We have SBO (station blackout). We've lost all AC power').
('Check the cause of the power loss')
[Narrator]. 'What caused this disastrous accident ?
(400 people's accounts)
'NHK interviewed more than 400 people to create a detailed reconstruction of the events.

(Animation of meltdown, labelled Simulation).
'We also drew on mountains of data to conduct simulations and confirm what happened'.
('Check the cooling status')
(The indicators are out for the 3A valve on the isolation condensers). (We can't confirm the operation status).
(First meltdown. Reactor 1).
[Narrator]. 'The first core meltdown occurred in Reactor 1. That set the stage for the crisis to expand'.
(What? The operation status of the isolation condensers ?).
(Steam from the “pig nose” ?).
(TEPCO video).
(Emergency. Cooling System).
[Narrator]. 'The emergency cooling system played a significant role in the disaster. Our investigation found that TEPCO missed cues that could have limited the scope of the crisis'.

(Senior crisis response official at the quake-proof building (emergency headquarters)).
'I suspected that the environment was becoming extremely tough for the reactor. I sometimes think 'wasn't there more we could have done ?'.

[Narrator] 'Consultation with experts also revealed a significant problem in the very foundations of the plant's safety protocols'.
(Footage outside the plant). (Water injection with fire engines)
'Officials used fire engines to inject water into the reactors as a last defence against a meltdown. But it turns out that much of the water leaked through an unexpected route'.
(Nuclear engineer).
'It was a blind spot. It was the first of many attempts, and they all failed'.

[3:00] (Kashiwazaki-Kariwa Nuclear Power Plant, Niigata).
'Have they really done enough to determine what caused the accident ? In communities debating whether to re-start idled nuclear plants, some people express doubts'.
(Hirohiko Izumida, Governor, Niigata Pref.)
'It seems that efforts to pinpoint the causes have slowed. It would be hard to convince citizens to push ahead with pro-nuclear policies without clarifying what went wrong'.

(Animation of meltdowns)
[Narrator] 'A series of meltdowns in the reactors at Fukushima Daiichi generated significant nuclear contamination',

('I can't confirm the drywell pressure')
('Check the cause')
[Narrator] 'Two years after the disaster, an independent investigation by NHK has uncovered new facts.
[Title]: (Meltdown. Oversights in the Reactor Cooling System).

[4:15]. (Yoshihiro Nemoto, Investigative reporter).
'It's been two years since one of the worst nuclear disasters in history, Level Seven, took place at Fukushima Daiichi. The Japanese government is crafting new safety standards that will set the criteria for re-starting nuclear reactors. A pre-requisite is wholly verifying what happened at Fukushima Daiichi. Have officials done that ? Before the accident, the government and the utility companies maintained that nuclear plants had foolproof safety measures, and that workers could handle any unforeseen events. But the reality was different. A larger-than-predicted tsnuami knocked out all power at the Fukushima Daiichi plant. Crisis unfolded inside the reactors all at once. The situation spiralled out of control.

[5:07] (Fukushima Daiichi accident timeline)

	R1 (in operation)	R2 (in operation)	R3 (in operation)	R4 (idle)
Mar 11,		Earthquake Tsunami		
	Loss of cooling system			
Mar 12	Meltdown			
	Hydrogen explosion			
Mar 13			Loss of cooling system	
			Meltdown	
Mar 14		Loss of cooling system	Hydrogen explosion	
		Meltdown		
Mar 15				Hydrogen explosion

'The first crisis was in Reactor 1. The cooling system failed, triggering a meltdown. Then a hydrogen explosion destroyed the building. Reactors 3 and 2 went into meltdown one after the next. Hydrogen explosions also rocked reactors 3 and 4. Massive amounts of radioactive materials flew into the atmosphere.

(Meltdown: The Fukushima Nuclear Crisis Behind the Scenes. (Broadcast in Jan. 2012)).
This kind of a disaster must never happen again.
(The Truth Behind the Chain of Meltdowns. (Broadcast in Aug. 2012)).
We saw a need to thoroughly confirm what happened at the scene of the accident. NHK has already two segments in a series called 'Meltdown', which brought new information to light. A third segment focusses on cooling the reactors; the only way a core meltdown could have been avoided.

(Picture of model of Fukushima Daiichi plant)
'First we look at Reactor 1. It's emergency cooling system stopped right after the tsunami. New evidence shows that operators could have picked up on trouble signs at a very early stage'.

[Narrator]. 'The first core meltdown occurred in Reactor 1.
(Main control room for reactors 1 and 2).
'Workers were monitoring both reactors 1 and 2 from the main control room'.

(March 11, 2011. 2:46 PM).
'On March 11th, 2011, a magnitude 9.0 earthquake struck'.
('Hit the ground')
('Confirm SCRAM')
(Full insertion of control rods in Reactor 1).
('The reactor is in automatic SCRAM. SCRAM confirmed). (The reactor automatically shut down).
(Reactor 2 is in automatic SCRAM. The reactor automatically shut down).
('Copy'). ('Shutdown of reactors 1 and 2 confirmed')

(Diagram of reactor).
[Narrator]. 'Control rods were inserted into the reactors' cores. This procedure stops nuclear fission, and is known as SCRAM. But the temperature inside the reactors remained high, at 300 degrees Celcius.
('Pay attention to reactor pressure, water level and temperature change'. Reactor 1, Reactor 2).
'Workers in the main control room had to quickly cool down the reactors. That was the only way to prevent the nuclear fuel inside from melting down'.
(Closing isolation condensers' 3A valve).

[Narrator]. 'Rapid cooling could damage the reactors, so the operators turned the cooling system on and off at intervals.
('Initiate RCIC. Check reactor water level'. Reactor 2, Reactor 1).
Up to this point, the cooling operation had proceeded according to plan. But things would soon take a sudden turn.
Fifty-one minutes after the quake.
(Emergency diesel generator tripped).
('We have SBO. We've lost all AC power')
('What time is it ?). (15:37).
('Check the cause').
('Irregularity at the metal-clad power center. Power supply is cut off').
('Copy. Check the cause of the power failure at Reactor 1')
('Yes, sir')
('What's the status of Reactor 2 ?'). ('Check the condition of the RCIC'). [But Reactor 2 may have no RCIC].
('RCIC discharge pressure is up') ('Copy').
('RCIC discharge pressure....') (Then lights went out).
[Narrator]. 'Only the emergency lights for Reactor 1 remained on.
('Go get all usable lights'). ('Yes, sir').
Just then, a worker from another building rushed in. (He was soaking wet).
('This is bad !') ('Seawater is pouring in').
('Are you all right ?') ('Hang on !')
(Footage of tsunami – Source: TEPCO).
[10:12]. [Narrator]. 'A massive tsunami, more than 13 meters high, washed over the plant.
(Animation of wave approaching and inside the plant).
The waves submerged a power panel at Reactor 1, cutting off electricity from the emergency diesel generator. Water also poured into the basement. Seawater flooded the emergency batteries. Now every source of power was lost.
('Clear the way') ('Hand them over')
What happened to the reactor's cooling system ?
(View of control panel, with switch)
('The indicators are out for the isolation condensers' 3A valve') ('I can't confirm the operation status')

(Graphic of Reactor with two condenser drums, labelled Isolation condensers)
Reactor 1 is equipped with two isolation condensers for emergency cooling. Hot steam from the reactor cools and condenses as it passes through a tank full of water. Once activated, this system will keep working without power. But workers had been operating the machinery at intervals. The system happened to be idle when all power was lost.
(Graphic of primary containment, labelled Reactor 1).
From that point on, the reactor quickly headed into meltdown. When it's tsunami hit, [cooling] water filled the reactor to a depth of 4.4 meters above the nuclear fuel rods, or "Top of Active Fuel". The [cooling] water level rapidly began to fall.
(Control room)
In the confusion, the operators in the main control room did not realise that the isolation condensers had been turned off just before the blackout. They would normally check whether the system was working, by looking at indicator lights above the lever. But when the power failed, those lights went out too. Was the emergency cooling system working or not ? Operators in the main control room could not tell.
(Graphic showing two primary containment vessels, with 'Main control room' between).

(Quake-proof building (emergency headquarters))
Three hundred fifty meters away, in the Quake-proof building, a false perception was spreading among officials. They mistakenly believed that the condensers were up and running.
(Masao Yoshida, Manager, Fukushima Daiichi Nuclear Power Plant)
Plant manager, Masao Yoshida, was supervising the overall crisis response. At his side was Masatoshi Fukura, a unit leader in charge of Reactors 1 through 4.
(Masatoshi Fukura, Unit Superintendent, reactors 1-4).
[Male questioner]. 'Mr Fukura, you assumed the isolation condensers were running even after the power outage'.
[Fukura]. 'Yes, that's what I assumed. I thought they were working'.
(Photo of 'Fax from quake-proof building to the Japanese government).
[Narrator]. 'Officials mistakenly believed for quite a while that Reactor 1 was safe. This is a fax, sent from the quake-proof building to the Japanese government.
(Close up of fax, with 'HPCI' – then 'Isolation condensers in operation').
In it, TEPCO officials report that the Isolation condensers were operating about five and half hours after all power had been lost.
(March 11, 2011, 9:50 PM. Nuclear and Industrial Safety Agency news conference).

[Official]. 'As we explained before, the Isolation condensers are up and running at Reactor 1. The water level is reportedly within a safe range'.
(Graphic of Reactor 1)
[14:30] [Narrator]. 'But at 9:50 pm, as government officials held a news conference, Reactor 1 was already on the verge of melting down.
(Anonymous interview)
Why did workers at the quake-proof building think the isolation condensers were operating ? A senior TEPCO official agreed to talk to us for the first time. He says it never occurred to him that the isolation condensers were idle, because they can run without electricity'.
(Senior official who was at the quake-proof building)
[Official] 'The isolation condenser is - in a sense - a static, non-electronic device, and requires no mechanical, revolutionary motion whatsoever. So even now, I think it is extremely effective. At the time, everybody, including me, was hoping that it was doing it's job'.

(Aerial footage, Ground Self-Defense Force video)
[Narrator]. 'TEPCO officials were unable to prevent a meltdown in Reactor 1. But our investigation reveals they could have noticed early on that the emergency cooling had stopped.
(View of control panel '1 hour after complete power failure (4:41 PM'))
At 4:41 pm, one hour into the blackout, batteries temporarily recovered. Gauges showing water levels inside the reactos came back on'.
('I can now see the water level for Reactor 1') ('It's 2,500 above Top of Active Fuel') ('The time is 16:41').
('Copy')
('Is the water level falling ?')
('It's lower than right after the emergency shutdown') ('I can't tell if the isolation condensers are operating or not')
[Narrator]. 'The water level was two and half meters above Top of Active Fuel. It had dropped nearly two meters in just one hour.
[So the Top of Active Fuel would be reached in little over an hour].
The rapid drop prompted operators in the main control room to suspect that the isolation condensers were not working'.
('Checking Reactor 1 water level')
('It's 2,500 above Top of Active Fuel')
[17:13]. 'Operators immediately relayed their information to the emergency headquarters in the quake-proof building. In one corner, workers began calculating what would happen to the reactor if things continued at the current rate.
(Progression prediction).
This is known as a “Progression prediction”.
(Internal document created by staff at the quake-proof building).
NHK has obtained a communication log from that time.
(1 hour to Top of Active Fuel)
It reads 'One hour to Top of Active Fuel. This means the emergency response team had received a shocking prediction. The reactor core would [start to] become exposed in just one hour'.
(Seawater has flowed in). (Tank possibly on fire)
But this information later became buried amid other data, and was never used. Multiple reactors were now in crisis. Plant manager Yoshida received more and more data'.
(Senior official who was at the quake-proof building)
[Official]. 'Important information kept coming in. We wanted to make sure the plant manager, the commander, got every bit. Members of each team had to wait for their turn to report to him. That was the situation we were in. With multiple accidents on such a major scale occurring at once, it's extremely difficult to share information with everyone concerned'.

(March 11, 2011. 4:44 PM)
[Narrator]. 'At 4:45 pm, workers had another opportunity to notice that the isolation condensers were not working'.
('What ? The operation status of the isolation condensers ?') ('Steam from the “pig nose” ?') ('Copy').
('There's been a call from the quake-proof building') ('They say the power generation team confirmed steam coming from the “pig nose”).
(View of outside of reactor building No 1. “Pig nose”)
[Narrator]. 'The “pig nose” refers to two ducts [pipes]. They allow steam generated by the isolation condensers to exit the reactor building.
(Animated graphic of isolation condenser)
People began questioning if rising steam meant the isolation condensers were working'.
(Quake-proof building (emergency headquarters))
A TEPCO employee dispatched from the quake-proof building confirmed the presence of steam. Officials there

continued to believe the emergency cooling system was working.
(Masatoshi Fukura, Unit Superintendent, reactors 1-4).
[Fukura]. 'We got reports saying steam was rising from the reactor building, and that the isolation condensers were on. That's why I assumed they were running. I thought if they stopped, I would probably be informed. That's the kind of assumption that was going through my head'.
(TEPCO accident investigation report) (Faint steam is drifting from the left-hand side).
[Narrator]. 'Workers at the site testified that the steam they saw at the time was faint.
(View of outside of reactor building No 1).
That, in fact, was a major sign of trouble'.

(Nine Mile Point Nuclear Station, New York, USA).
[Narrator]. 'What does steam discharged by a working isolation condenser look like. The United States is the leading producer of nuclear power. The Nine Mile Point Nuclear Station was built at around the same time as the Fukushima Daiichi plant. Every four years, it's operators put the isolation condensers through a start-up test. They say every worker knows what happens when the emergency cooling device is turned on'.
(Senior official. Nine Mile Point Nuclear Station).
[Official]. 'When the emergency condensers are initiated, it takes whatever energy is in the reactor and just boils water'.
(Footage from start-up test).
[Narrator]. 'These photos were taken three years ago, during a start-up test. Instead of being faint, a thick cloud of steam engulfs the whole building'.
[Official]. 'There's a ton of steam and it sounds loud. It's a big rush. So it'll scare you. It'll knock your socks off if you're not careful'.
[Narrator]. 'US operators say faint steam emerges two to three hours after the isolation condensers are turned off'.
[21:56]. (View of TEPCO accident investigation report).
[Narrator]. 'Reactor 1 was heading into meltdown.
(Faint steam is drifting out from the left-hand side)
It turns out that the faint steam was a significant sign of the impending crisis'.
(TEPCO video. Isolation condensers (Reactor 1, Fukshima Daiichi))
Why didn't TEPCO officials realise it ? We discovered that had not activated the isolation condensers in Reactor 1 for about 40 years. [This beggars belief].

(Anonymous interview)
None of the operations staff had ever seen what kind of steam the condensers discharge when turned on'.
(Senior official who was at the quake-proof building).
[Official]. 'I have never seen a working condenser. Any steam discharge was taken as an affirmation that the condensers were active. No-one declared that they were idle. I guess that we were unable to provide the kind of information to plant managers that would have pushed them to do something'.
(TEPCO head office)
[Narrator]. 'Operators and managers had a flawed understanding of a critical cooling system. TEPCO is responsible for the accident. To what extent have officials verified what happened ?

(Meeting room)
[23:38]. Last September [2012], the company launched an in-house review of it's response to the accident'.
[Attendee]. 'Faint'.
[Narrator]. 'The faint steam presented operators with a decisive opportunity to notice that the isolation condensers were not working. An internal TEPCO panel charged with confirming details of the accident also focussed on this information. But people taking part in one meeting we filmed were divided over the significance of the faint steam'.
(Employee who was at the quake-proof building).
[Employee 1]. 'Some witness said the steam looked faint and still'.
[Employee 2]. 'Doesn't faint suggest they were working ?'
[Employee 3]. 'Everyone sees things differently. So the questions of how much steam is enough to say that the isolation condensers were active will vary from person to person'. [This could not be true if they had ever seen the real thing].
[Narrator]. 'Officials called the meeting to review the findings of the three-month long internal investigation. A senior member of the nuclear division concluded that TEPCO workers lacked basic technical skills'.
(Senior official, TEPCO nuclear division).
[Senior official]. 'We're running a live plant. It's a living creature. We must know what kind of creature it is in order to operate it safely. I suppose in some ways workers lacked focus or lacked the right kinds of operational skills'.
(View of outside of plant).
[Narrator]. 'TEPCO officials missed a number of critical opportunities.
(8 hours after complete power failure (March 11, about 11:50 PM)).

Then, eight hours after all power was lost, workers had been dealing with multiple reactors at the same time. Then the situation became critical in Reactor 1'.
(View of pressure gauge)
('Checking drywell pressure') ('600 kilopascals !') ('Drywell pressure unusually high at 600 kilopascals !')
('Drywell pressure unusually high. Understood !')

(Graphic of Reactor 1).
[Narrator]. 'The temperature of the nuclear fuel in Reactor 1 soared, and released hydrogen that filled up the building'.
(Graphic of Reactor 2 and Reactor 1)
[Narrator]. 'Workers at the scene had been focussed on Reactor 2, but the first to melt down was Reactor 1.
(12 hours after complete power failure (March 12, about 4:00 AM, showing radiation probe in use).
At about 4 o'clock the following morning, in the main control room..'
('Radiation is high near Reactor 1')
Measurements showed an abnormally high level of radiation'.
(View of the outside of the plant) (24 hours after complete power failure (March 12, 3:36 PM)).
Twenty four hours after the power went out'.
(Explosion)
('Wear your masks !') ('Check drywell pressure !') ('Unable to check drywell pressure !')
('Confirm the cause !')
[Narrator]. 'First a failure in the [emergency core] cooling system caused a meltdown in Reactor 1. Then hydrogen inside exploded. The situation went downhill from there'. [It is unreasonable to expect such events to be contained].

(Yoshihiro Nemoto, Investigative reporter).
[27:58]. 'Multiple reactors simultaneously lost power. More aftershocks and tsunami could come. Even if operators had noticed the isolation condensers weren't working, they may not have been able to prevent a meltdown. They did not know how the critical cooling devices would function in a disaster. It was therefore impossible for them to make the right decisions or take appropriate actions. How well did the operators understand each of the huge array of technologies used at the plant ? Our investigation revealed another challenge; cooling nuclear reactors. The emergency cooling system wasn't operating, so workers resorted to pumping water from fire engines outside. Workers at the site came up with this as a last-ditch method of getting water into Reactor 1'.

(Fukushima Daiichi accident timeline)

	R1 (in operation)	R2 (in operation)	R3 (in operation)	R4 (idle)
Mar 11,		Earthquake		
		Tsunami		
	Loss of cooling system			
Mar 12	Meltdown			
	Hydrogen explosion			
Mar 13			Loss of cooling system	
			Meltdown	
Mar 14		Loss of cooling system	Hydrogen explosion	
		Meltdown		
Mar 15				Hydrogen explosion

[Nemoto]. 'Reactor 3 was the site of the next crisis. It's batteries survived the tsunami and it's cooling system was running, but it was only a matter of time before the batteries would run out. [Moreover, I think that – unlike R1 - R2, R3 need electricity to run the emergency cooling system]. At that time, operation staff were preparing to inject water using fire engines. But this last-ditch method had a major problem'.

(Main control room for reactors 3 and 4).
[Narrator]. 'In the main control room for Reactors 3 and 4...'.
('The reactor pressure is plummeting !').
('The coling system is functional. But it could stop at any time !')
('We'll lower the reactor pressure to prepare for substitute water injection').
('Get ready to open the valve for injecting water into the reactor').
[29:51]. ('Will do !')

(View of outside, showing fire hoses and 'Substitute water injection').
[Narrator]. 'Substitute water injection involves cooling a reactor by flushing it with water from fire engines or pumps. A nuclear reactor is surrounded by a network of pipes. If connected in the right way, they can be used to send water into the reactor.
(Graphic of reactor).
To do this, it is necessary to release the steam from the reactor to reduce the pressure inside. [But this will increase the rate of steam evolution]. Water can't flow in if the pressure is too high. But the workers had to inject water right away, otherwise any water remaining in the reactor could quickly evaporate and speed up the meltdown process. [Also, the meltdown could result in the molten fuel forming a critical mass, with much increased heat release].

(Animated graphic of reactor vessel and pipework)
The operators needed to manipulate valves along the convoluted network of pipes, to ensure that the water travelled along a single path. That would allow them to quickly fill the reactor with water and prevent a meltdown. The problem was that the workers had never practised using fire engines to pump in water.
('The valve that's part of the core spray system is confirmed').
('Understood').
(Fire engines start injecting water (March 13, 9:25 AM)).
At 9:25 am on March 13th, operators began pumping water from fire engines into the nuclear reactor'.
(Graph of Water injected from fire engines. Estimate based on TEPCO's data).
Experts estimate that fire engines pumped more than 400 tons of water that day. That should have been enough to cool the nuclear fuel. But the following day...'.
(Explosion). (Hydrogen explosion in Reactor 3. March 14, 11:01 AM)
Hydrogen inside Reactor 3 exploded. The water from the fire engines did not prevent a meltdown'.

(Shibuya, Tokyo).
Using fire engines to pump water was a fundamental part of the safety response. Why didn't it work ? We performed a detailed analysis with help from experts in nuclear power and fluid engineering. The experts questioned whether there was a problem with the route used to inject water.
(Steam condenser)
They homed in on a device called a “Steam condenser”. The Steam condensers are outside the injection route. They take steam used for power generation, convert it into water, and then send the water out. Normally there's hardly any water inside'.
[33:24]. (TEPCO news conference. March 28, 2011).
But two weeks after the accident, TEPCO officials revealed that the steam condensers contained an unusually large amount of water'.
[TEPCO official]. 'The steam condensers seemed full of water at Reactors 2 and 3. The steam condensers seemed full of water'.

(Meeting of experts).
[Narrator]. 'Could water from the fire engines have flowed into the steam condensers ?
NHK secretly obtained a diagram of Reactor 3. We studied the complex piping system along with the experts'.
[Expert 1]. 'Any valves ? There's a manual one. I wonder if there were any other outlets.
[Expert 2]. 'Probably not on the reactor side'.
[Narrator]. 'One of the experts had worked on designing nuclear power plants. He located a path'.
(Hiroshi Miyano, Professor, Hosei University. (Former executive at nuclear plant supplier).
[Miyano]. 'It starts with the line from the fire engine'.
[Narrator]. 'The single line, highlighted in blue, is for sending water from fire engines. A thin line branches off, and connects to the steam condensers'.
[Miyano]. 'This is the line that leads to steam condensers. It continues here'.
[Narrator]. 'But when we take a closer look, the line comes back, to a low-pressure condensate pump.
(Low-pressure condensate pump).
Before the line reaches the steam condensers, it hits a pump that should block the water flow. [This is wrong, since it is a rotodynamic pump].
(Animated diagram of piping and pump).
From the piping that sends water from fire engines into the reactors, a branch splits off and leads to the steam condensers. The pump sits along this branch. Rotating blades inside the pump typically circulate water from the steam condensers. Under normal [operating] conditions, hydraulic pressure from below would have blocked the water from the fire engines'. [This is clearly a fundamental design error, never spotted in over 40 years].

(Tokyo University of Marine Science and Technology).

But the pump had stopped working when the tsunami knocked out the power supply. With the experts' help, we simulated the events leading up to the disaster.
(Pump. Steam condenser).
The blue pipes represent the line from the steam condensers. The red one above shows how water from the fire engines would have flowed. The red tinted water represent water from the fire engines. Normally, the water should stop at the pump, but... the red water goes through the pump and leaks into the tank that represents the steam condensers. The pump at Reactor 3 was not operational. The lack of pressure from below allowed water from the fire engines to pass right through. It then flowed into the condensers, where the hydraulic pressure was lower. The operators [and the designers] had never imagined that the plant would completely lose power. That's why they didn't realise that the water could flow along an alternate route.

(Masahiro Osakabe. Professsor (fluid engineering), Tokyo University of Marine Science and Technology
[Osakabe]. 'The pump's failure created a new route. That was a blind spot. No-one had thought of this possibility. [This is an example of why nuclear power plants are inherently dangerous].

(Piacenza, Italy, then SIET).
[Narrator]. 'The new route was a major reason for the meltdown. SIET in northern Italy is one of the world's largest experimental facilities. It can test high pressure systems. Nuclear plant manufacturers worldwide use it's laboratories. This device simulates a nuclear reactor. Our experts used it to re-enact what happened when fire engines injected water at the Fukushima Daiichi plant'.
(Fabio Inzoli, Professor, Politecnico di Milano).
[Inzoli]. 'I think there is a great interest about water at Fukushima. From a scientific point of view, there is a great interest at international level, I think'.
[38:38]. [Narrator]. 'Engineers assembled parts to duplicate the conditions at Reactor 3. They even considered the thickness [diameter] and length of the piping to the reactor, as well as differences in height. To figure out how much water had leaked, the engineers looked closely at the section where the water flow splits between the reactor and the steam condensers. We used a high speed camera to record their experiment.
(Reactor. Fire engine – later '55% (to steam condensers)').
The horizontal pipe represents the line from the fire engine to the reactor. The vertical one - above - simulates the leak to the steam condensers. When the fire engines started pumping water, the [atmospheric] pressure in the reactor was 3.5 atmospheres, compared to 1 atmosphere in the condensers. The engineers re-created the pressure levels and observed the water flow. Then, water begins gushing into the alternate path. The flow is clearly stronger than the flow to the reactor. The experts used the results to calculate how much water had flowed. Their calculations show that just 45 per cent of the water from the fire engines reached Reactor 3, but 55 per cent leaked into the steam condensers'.

(Marco Ricotti, Professor, Politechnico di Milano).
[Ricotti]. 'If we need to inject water into the reactor pressure vessel, er, we need to avoid any leakage in the line. This is an important topic and must be duly investigated'.
(Experts Meeting. 'Shibuya, Tokyo').
[Narrator]. 'The finding is stunning. 55 per cent of the water pumped from the fire engines leaked.
(Masanori Naitoh. Director (Safety Analysis). The Institute of Applied Energy).
Japanese experts did another simulation. It shows that a meltdown could have been avoided if the leak had been limited to 25 per cent or less.
(Graphic of reactor).
If the water pumped in by the fire engines had made it to the reactor from the start of the injection process, a meltdown in Reactor 3 might have been avoided'.
(Isao Kataoka. Professor (Severe accident management), Osaka University).
[Kataoka]. 'The plant's operators never imagined they would have to rely completely on fire engines for water. [Then what was the point of using them at all ?] And their initial attempt was during a crisis'. [Why had it never been tested ?]
(Masahiro Osakabe, Professor (fluid engineering), Tokyo University of Marine Science and Technology).
[Osakabe]. 'A leak can make a major difference. That was regrettable. A real pity. [An astonishing failing by the utility and the safety agencies].
[Narrator]. 'Injecting water from fire engines into the reactor failed to prevent a meltdown. The reason was a pump connected to the steam condensers. This pump is like the ones at Fukushima Daiichi. The route that diverted the water gradually narrows. At the very end, the diameter is barely three centimeters. This slender pipe defeated a last-ditch attempt to stop a meltdown.

(Quake-proof building (emergency headquarters)).
[42:33]. TEPCO officials were aware at the time that their efforts weren't going well.
(TEPCO video conference. March 14, about 3:36 AM).

TEPCO recorded eight hundred and six hours of video conferences among workers trying to contain the crisis. The footage contains a conversation from one of those meetings. The discussion was between Plant Manager Masao Yoshida, who was in the quake-proof building, and Vice-President Sakae Muto, who was in charge of the nuclear power division'.
[Muto]. 'Are you saying that you've injected enough water to fill the reactor vessel ?'
[Yoshida]. 'Correct'.
[Muto]. 'So what's happening then ? Is there a leak somewhere ?'.
[Yoshida]. 'As in Reactor 1, the water level in Reactor 3 isn't rising, even though we are injecting water. This means there's a high possibility of a bypass flow.'.
[Muto]. 'You mean there's an alternate route ?'.
[Yoshida]. 'Right'.

(National Diet Investigation Commission report).
[Narrator]. 'Lawmakers and governmental authorities commissioned their own investigations into the Fukushima nuclear accident. But none of their reports mentioned the fact that water from the fire engines had leaked.
(Onagawa Nuclear Power Plant. Tohoku Electric Power Co.)
After the accident in Fukushima, Japanese power companies dispatched fire engines and water pumps to their nuclear facilities. Workers hold drills to firm up procedures. But they haven't done any tests to see whether they can inject water into reactors without it leaking.
The Nuclear Regulation Authority is Japan's nuclear safety watchdog. We asked officials what they thought.
(Toyoshi Fuketa. Commissioner, Nuclear Regulation Authority).
[Fuketa]. 'There's been little investigation so far into water injection with fire engines. The nuclear plant operators [utilities] actually deal with accidents and our staff would wind up discussing the situation face-to-face, much like this. Or huddling together over a diagram at the site'. [Only after the fact ? Surely a nuclear regulator should be pro-active ?]

(Nine Mile Point Nuclear Station, New York, USA).
[Narrator]. 'What can be done to prevent meltdowns ? The United States is the world's leading producer of nuclear power. Industry officials there have gradually modified their approach.
(Fukushima Project).
The reactors at this plant are the same as the ones at Fukushima Daiichi. The operators [utility ?] launched a safety management project after the accident in Japan.
[American 1] 'And the new way we're going to business we're going to take that spool piece and make it permanent'.
[American 2]. 'Rather than have to.. have the operators fool with flanges or anything like that'.
[Narrator]. 'Officials plan to install designated pipes so workers can pump water from a location near the reactor. And they have increased the number of powerful pumps for injecting water from outside. This gives them various ways to cool the reactors'.

(Frank Payne, Executive, Nine Mile Point Nuclear Station).
[Payne]. 'After Fukushima, we realised that we needed to have .. a different capability.. not just to be able to hook up from inside the plant, but to be able to hook up from outside the plant.. and to have more locations. So part of the designs we're putting in place now [40 years after startup] will give us this flexibility. We'll be able to inject water even if we can't get into the building'.

(Footage of one of the explosions).
[Narrator]. 'Two years after the accident in Fukushima, oversights in the reactor cooling system have finally come to light. The question is 'how can we all make the best use of this information ?'

(Yoshihiro Nemoto, Investigative reporter).
(Plans for Dedicated Pipes (Boiling water reactors).
Chugoku Electric, Installing, Hokuriku Electric, No plans, Tokyo Electric, Under planning, on the West coast; Chubu Electric, Installing, Japan Atomic Power, Installed, Tohoku Electric, No plans on the East Coast).
[Nemoto]. 'Some Japanese utilities are installing dedicated water injection pipes like the ones [planned] in the US. Installation is complete at the Tokai Daiini plant. It's reactors are the same as Fukushima's. Installation is progressing or is being planned at some other plants. But US and Japanese operators are not exchanging information on the issue of alternate lines. The steps being taken do not fully reflect about the March 2011 accident. Post-disaster safety measures included dispatching fire engines and water pumps to nuclear plants. Government authorities and power company officials then declared that there would never be another accident like Fukushima. [This does not change the physics]. But officials have not fully probed the issues, including water injection with fire engines. Two years have passed. Even as we continue with our investigation, we have the sense that it's getting harder to get to the bottom of the disaster. As time goes by, memories of the people involved begin to fade, and the public gradually loses interest. There are

constraints. High radiation levels make it impossible to conduct a thorough investigation. Still, there is much we can do. Our experiments and analysis are examples. Such simulations can't perfectly re-create the accident. But they can reveal weaknesses in safety measures and show where more attention is needed. We've touched on many issues in this programme, issues no-one was aware of before the accident. No nuclear plant is completely safe. The accident in Fukushima should prompt every person involved in nuclear power to work tirelessly for better safety. There must be no more Fukushimas. [The only way to be sure is to shut down all nuclear power]. We'll keep digging to uncover the truth about the accident.

[End].