Lorena Packaged Emulsion Plant Explosion, 11 November 2004

ORICA MINING SERVICES

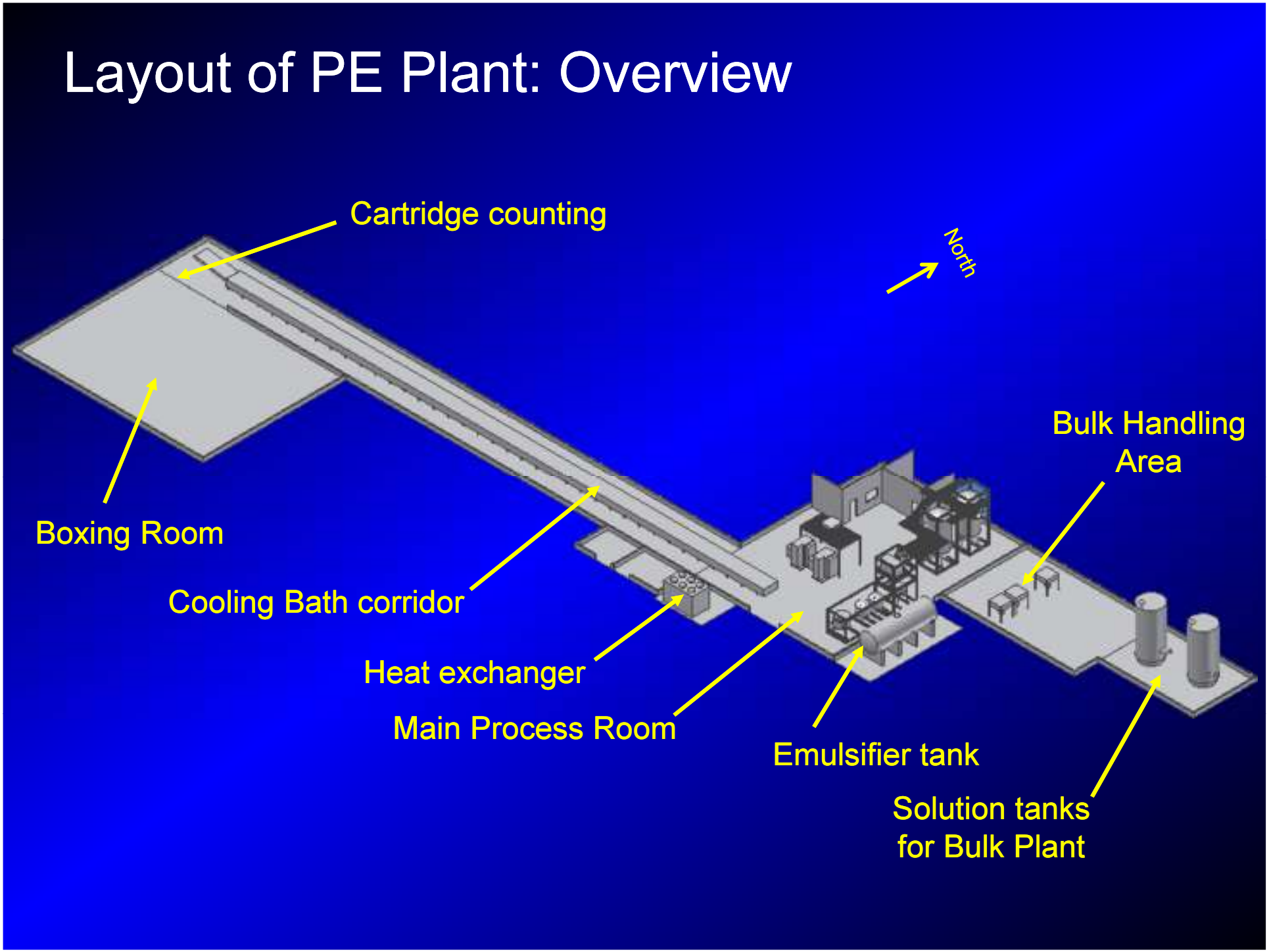
Prefatory note

The Packaged Emulsions Plant located at Lorena, Brazil was completely destroyed by the explosion that occurred on November 11, 2004. As a result of this, very little direct physical evidence of the causes of the explosion survived. The following represents Orica's best estimates and conclusions regarding this tragic accident, based on scientific investigation of the recovered debris. However, due to the magnitude and extent of the destruction, and the limited direct physical evidence that remained afterwards, it must be understood that the conclusions set forth herein necessarily contain a degree of speculation, conjecture and hypothesis.

Outline

- Layout of PE plant
- Timeline of events from witness statements
  - Observations
  - Personnel movements
- Debris recovery and analysis
- Summary of event and consequences
- Recommendations

Layout of PE Plant: Overview

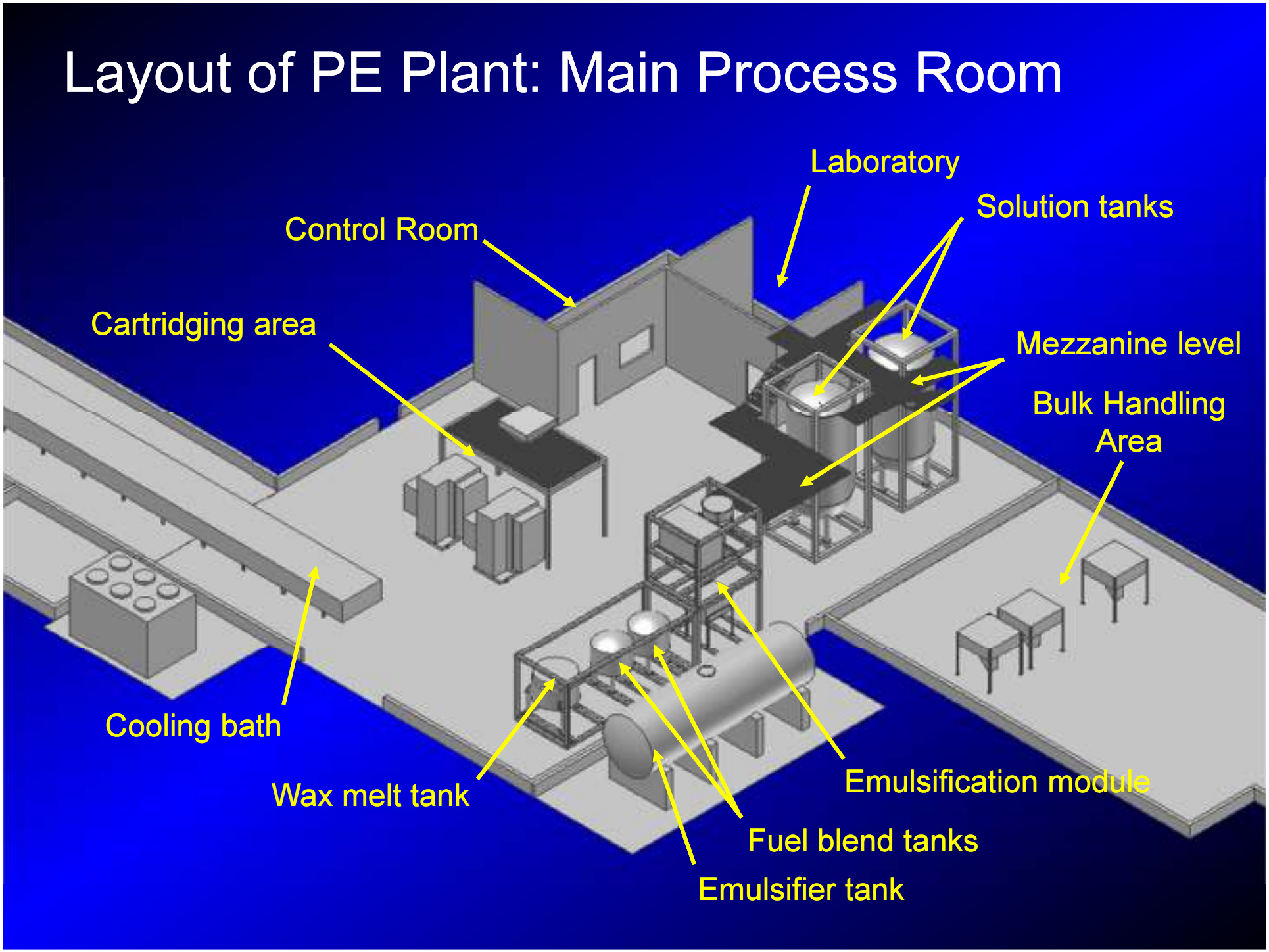


Layout of PE Plant: Overview

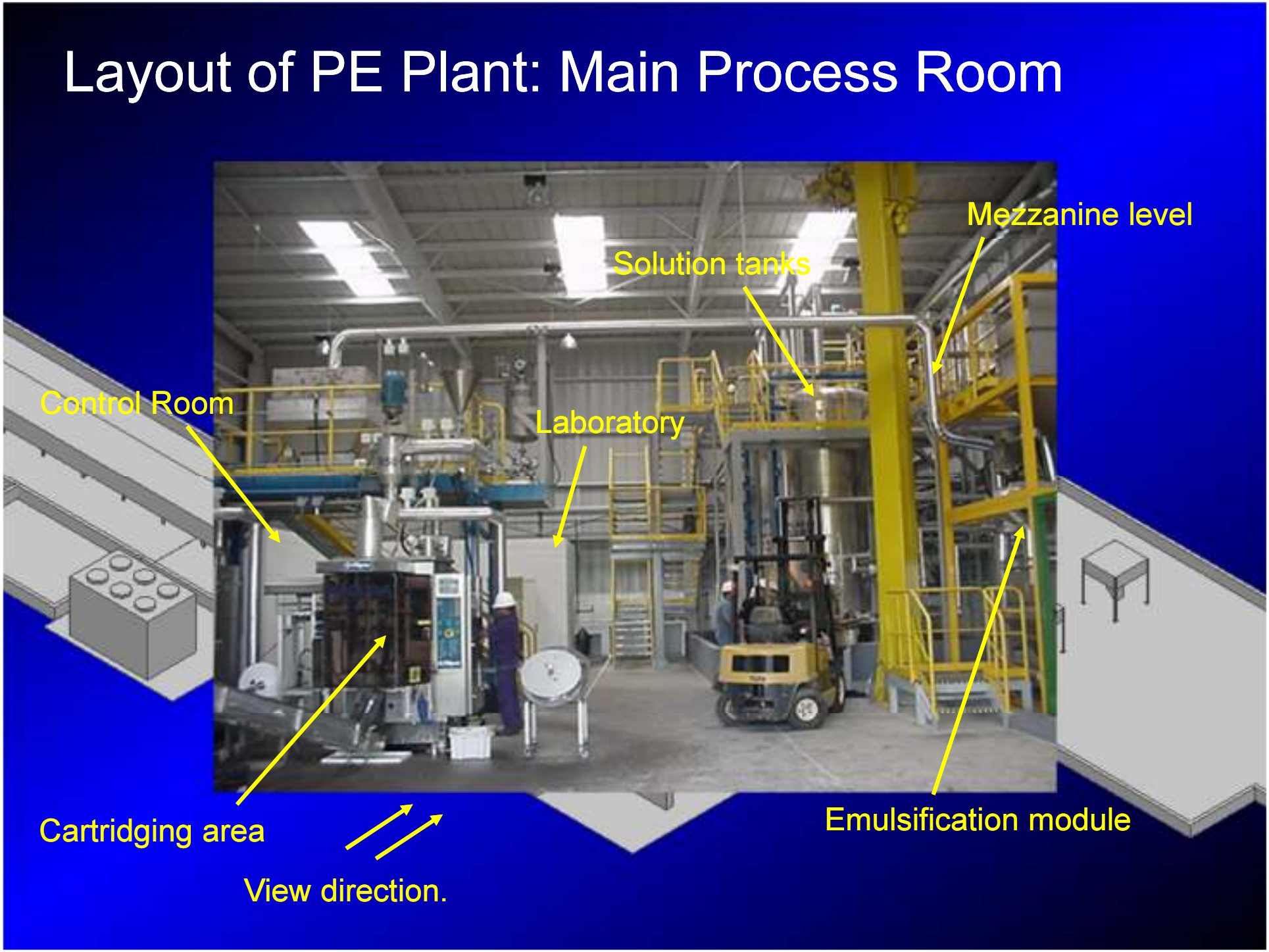
Layout of PE Plant: Overview

View direction.

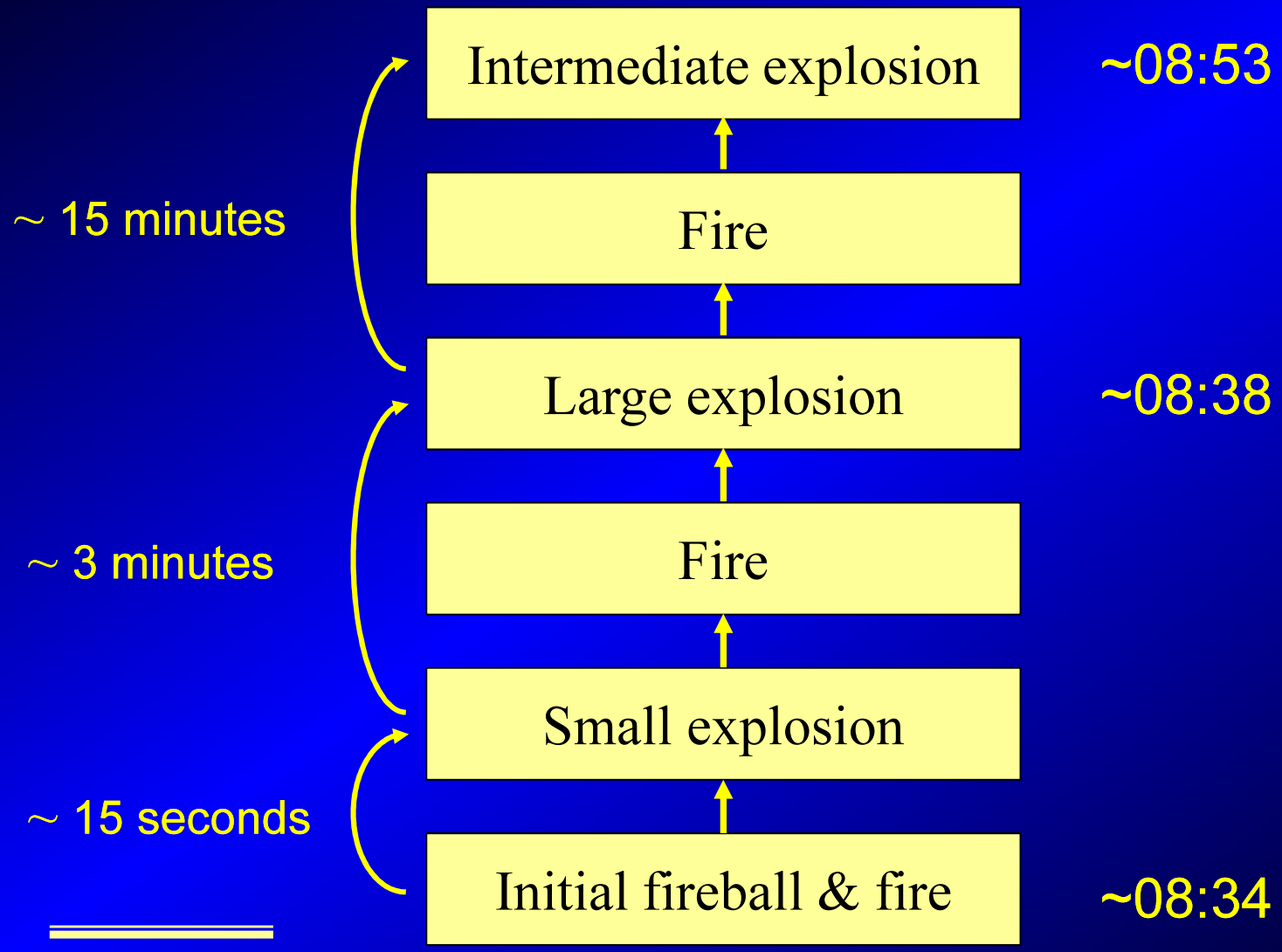
Layout of PE Plant: Main Process Room



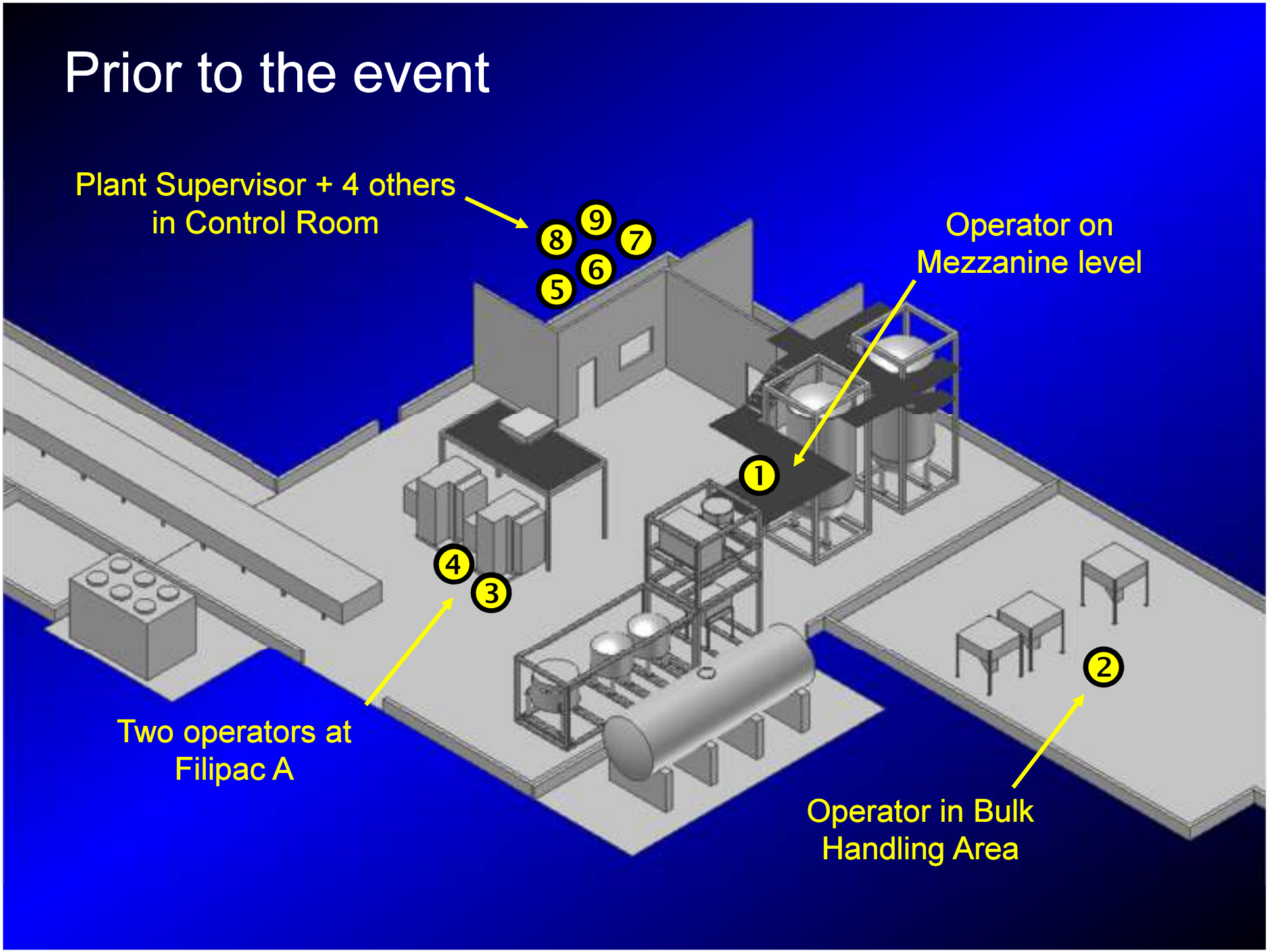
Layout of PE Plant: Main Process Room



Timeline according to witness statements



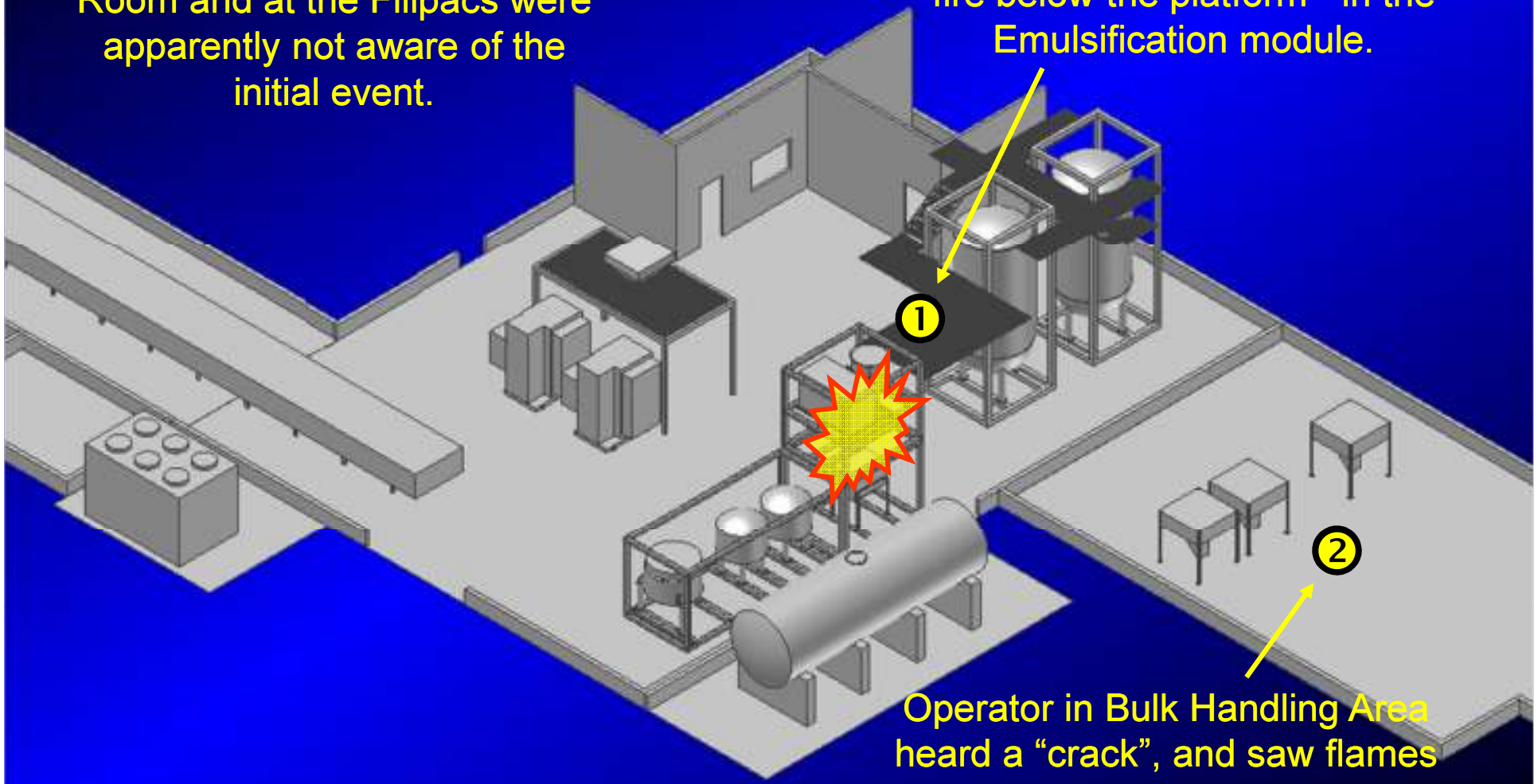
Prior to the event



The initial fireball and fire

The personnel in the Control Room and at the Filipacs were apparently not aware of the initial event.

Operator on Mezzanine level saw a “bright, sharp, yellow fire below the platform” in the Emulsification module.



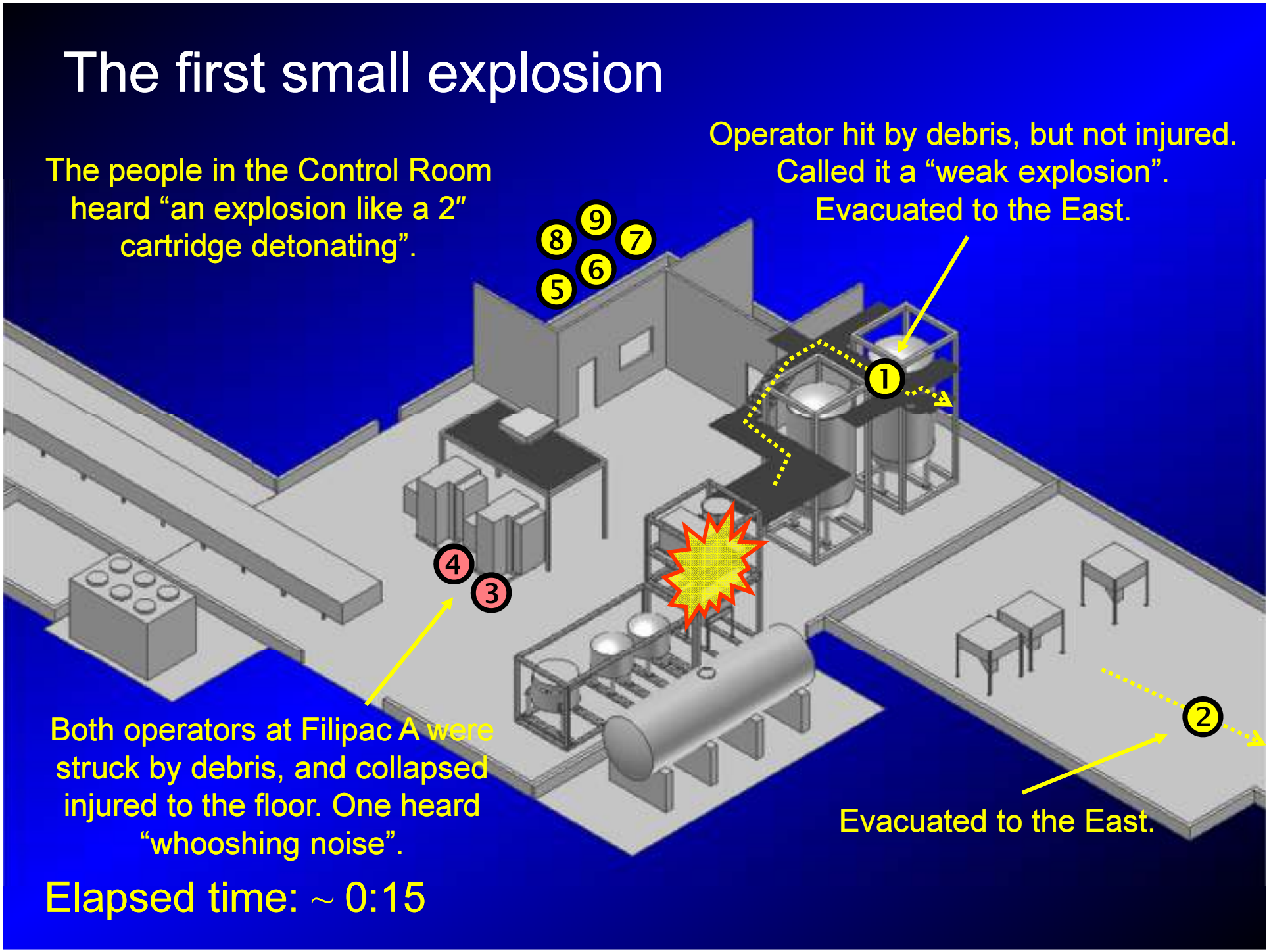
Operator in Bulk Handling Area heard a “crack”, and saw flames through the window to the Emulsification module.

Elapsed time: 0:00

The first small explosion

The people in the Control Room heard “an explosion like a 2″ cartridge detonating”.

Operator hit by debris, but not injured. Called it a “weak explosion”. Evacuated to the East.



Both operators at Filipac A were struck by debris, and collapsed injured to the floor. One heard “whooshing noise”.

Evacuated to the East.

Elapsed time: ~ 0:15

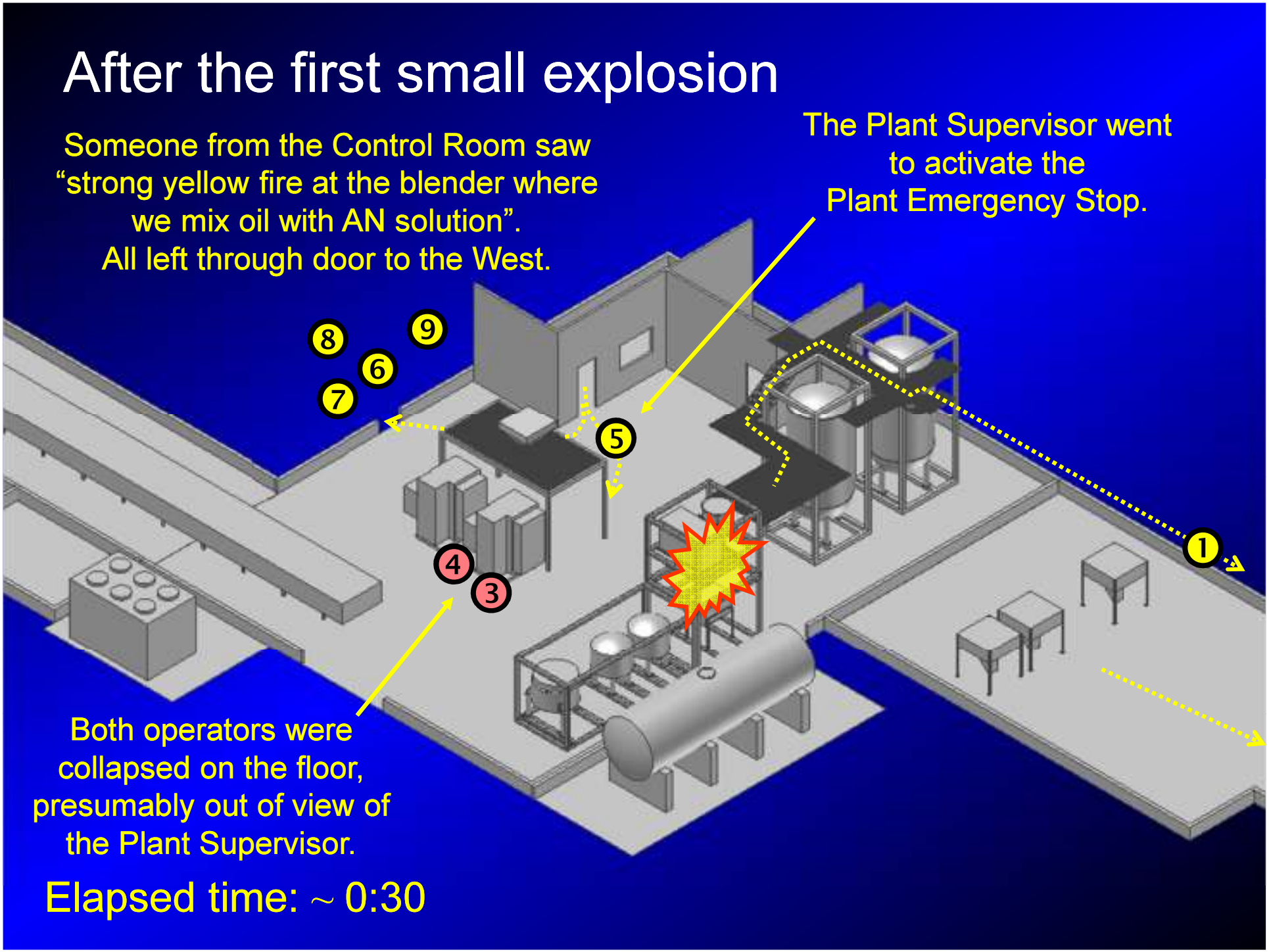
Possible initial event

- Steam cleaning or water ingress into Aluminium system
- Lumping of Aluminium and possible evolution of hydrogen from water/aluminium reaction
- Friction event in Aluminium metering augers
- Friction/heat ignited hydrogen/aluminium dust
- Dislodgement of aluminium system allowing loss of containment of aluminium causing fire

After the first small explosion

Someone from the Control Room saw
“strong yellow fire at the blender where
we mix oil with AN solution”.
All left through door to the West.

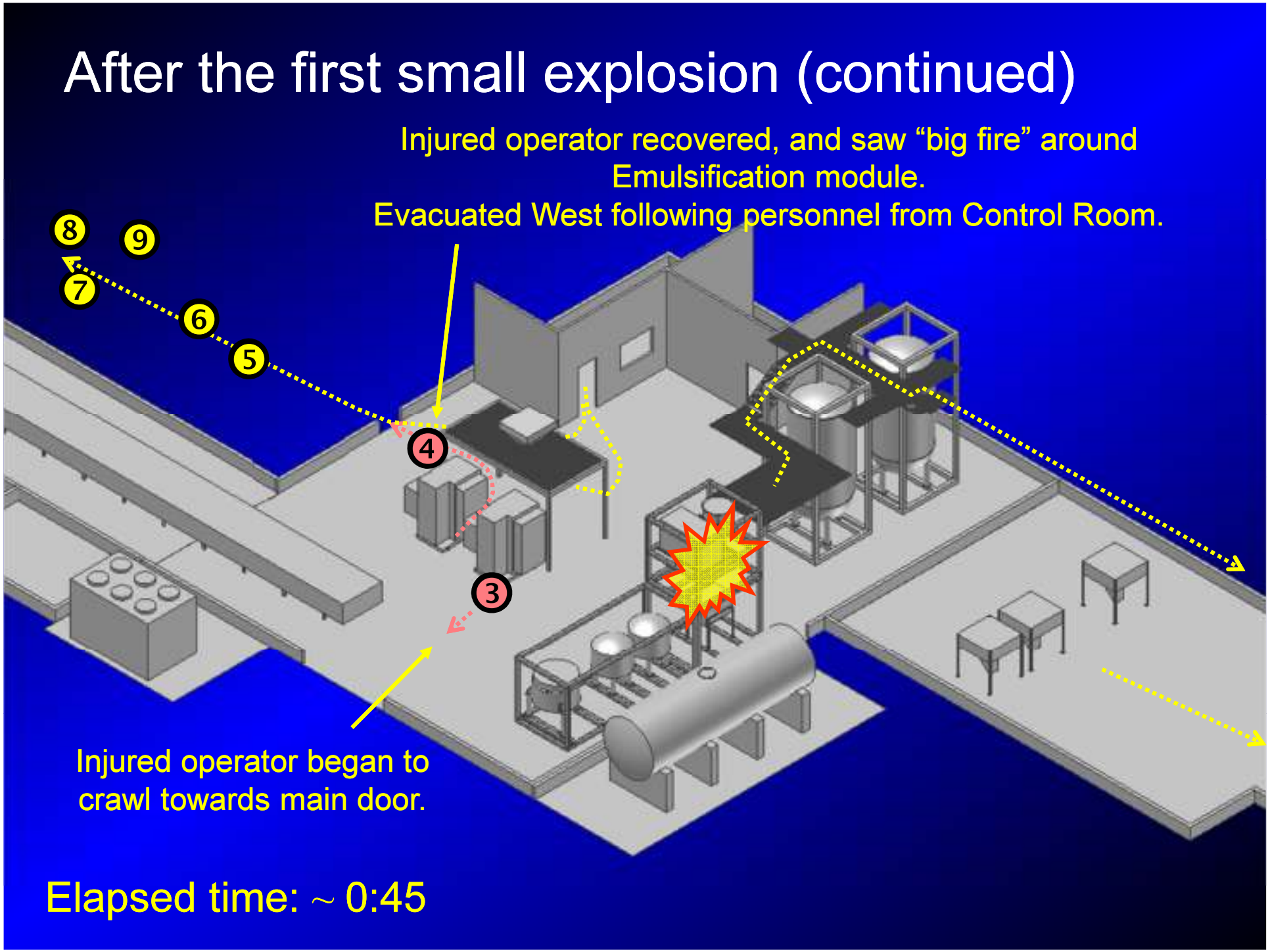
The Plant Supervisor went
to activate the
Plant Emergency Stop.



Both operators were
collapsed on the floor,
presumably out of view of
the Plant Supervisor.

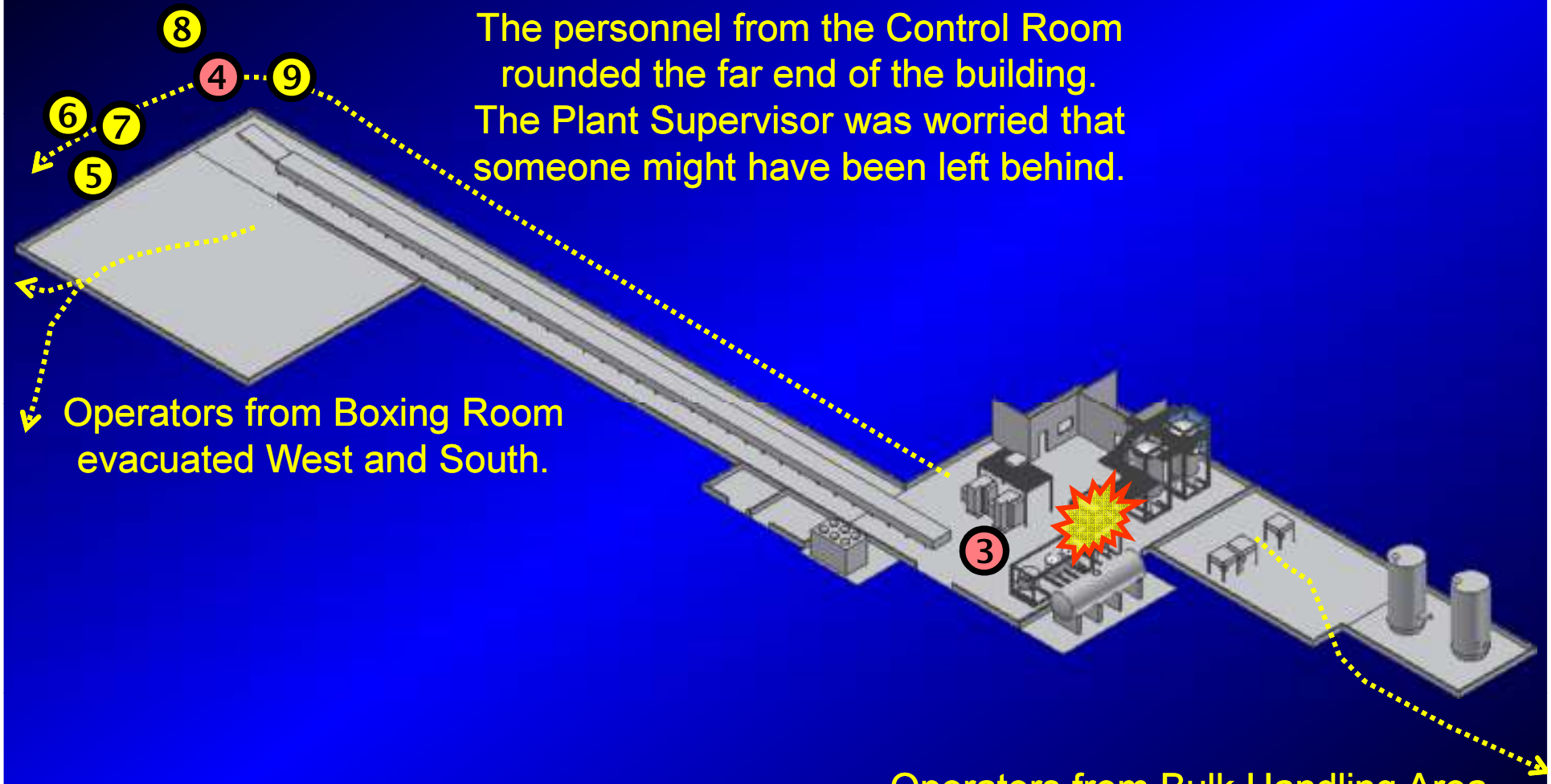
Elapsed time: ~ 0:30

After the first small explosion (continued)



Elapsed time: ~ 0:45

During the fire



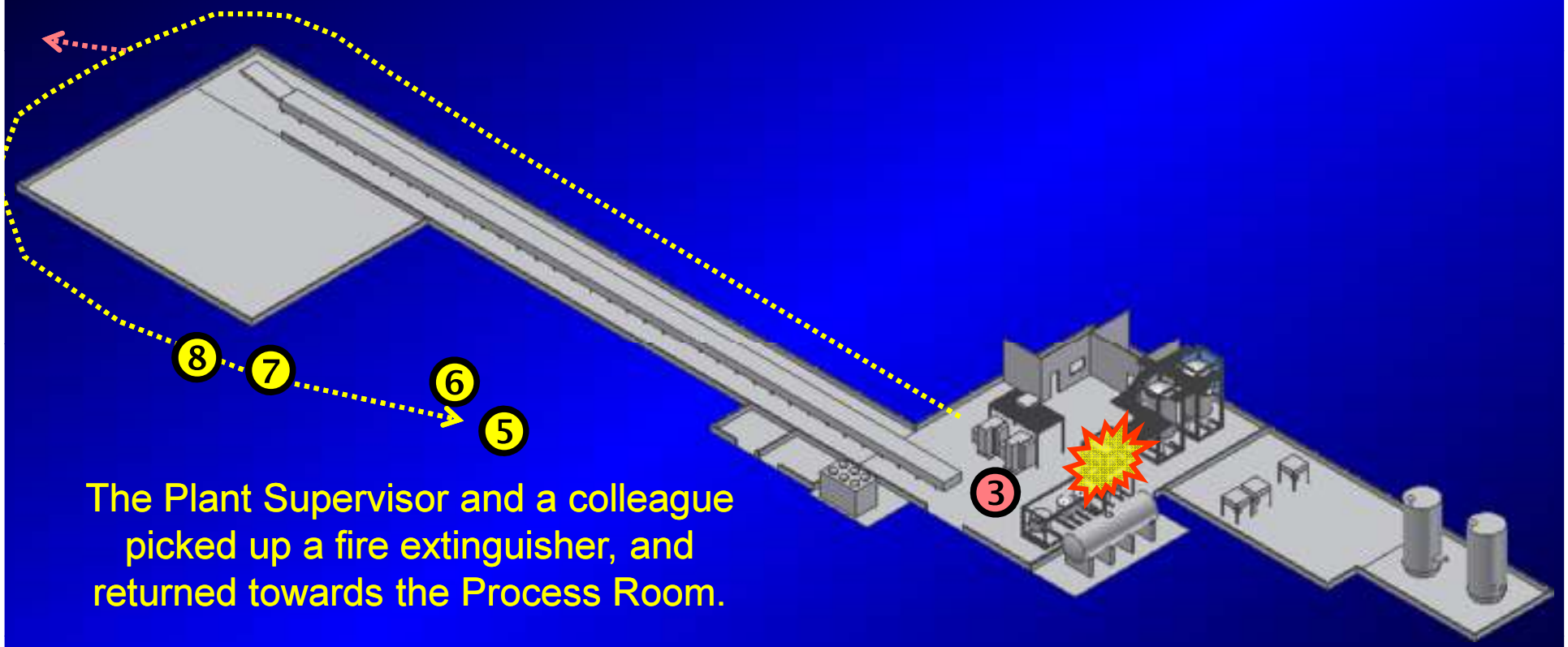
The personnel from the Control Room rounded the far end of the building. The Plant Supervisor was worried that someone might have been left behind.

Operators from Boxing Room evacuated West and South.

Operators from Bulk Handling Area and Bulk Plant evacuated East.

Elapsed time: ~ 2:00

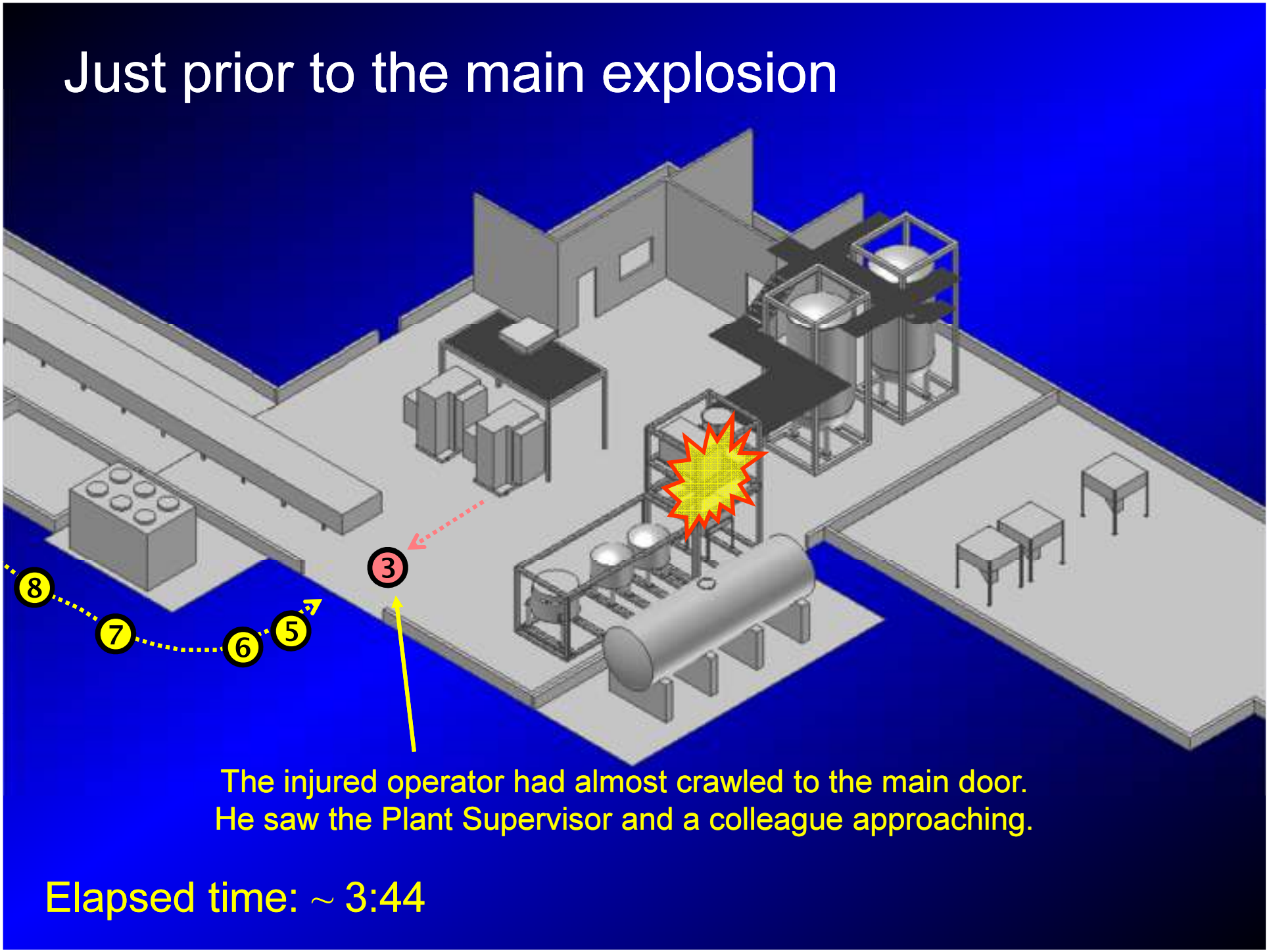
During the fire (continued)



The Plant Supervisor and a colleague picked up a fire extinguisher, and returned towards the Process Room.

Elapsed time: ~ 3:00

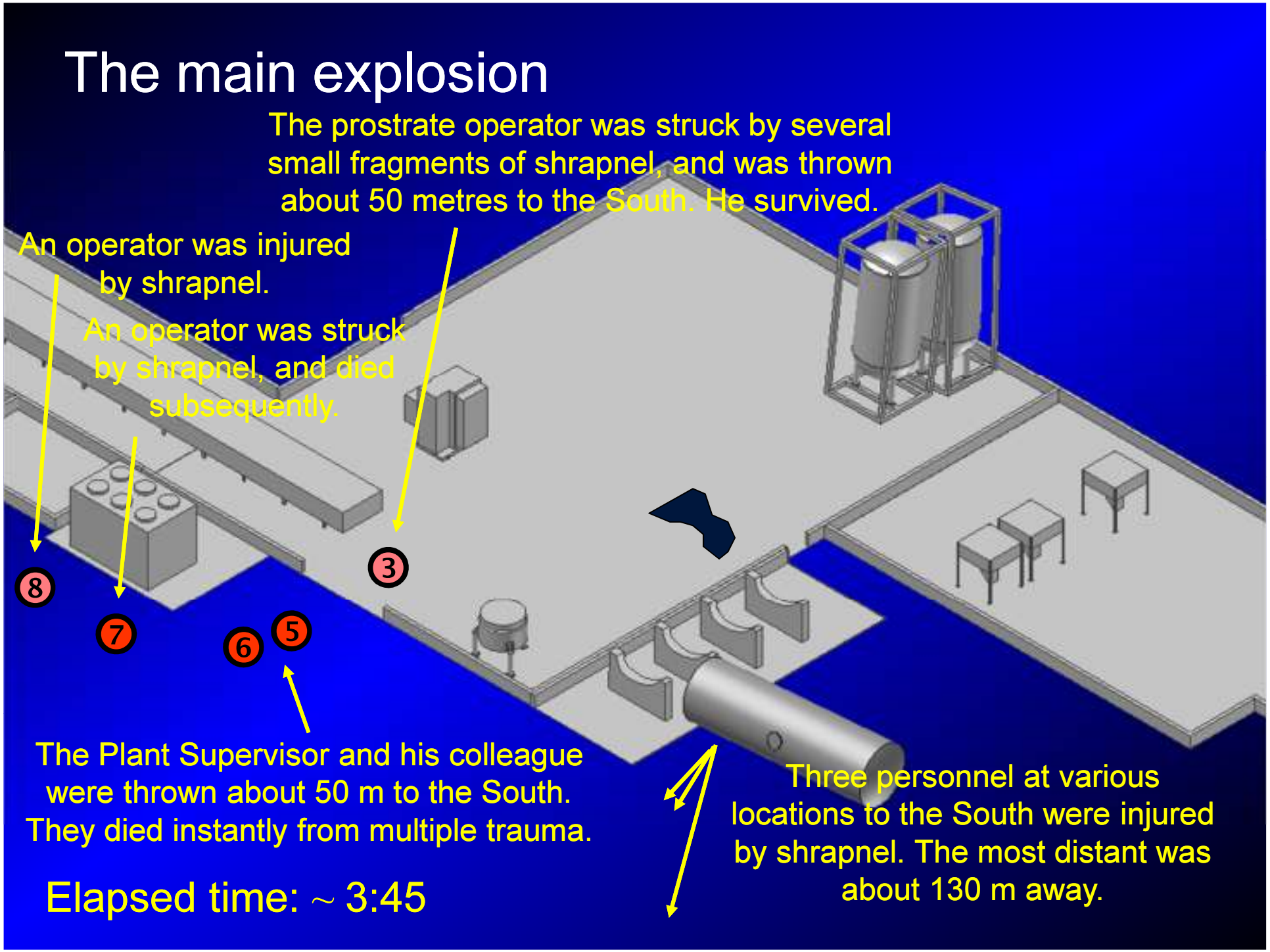
Just prior to the main explosion



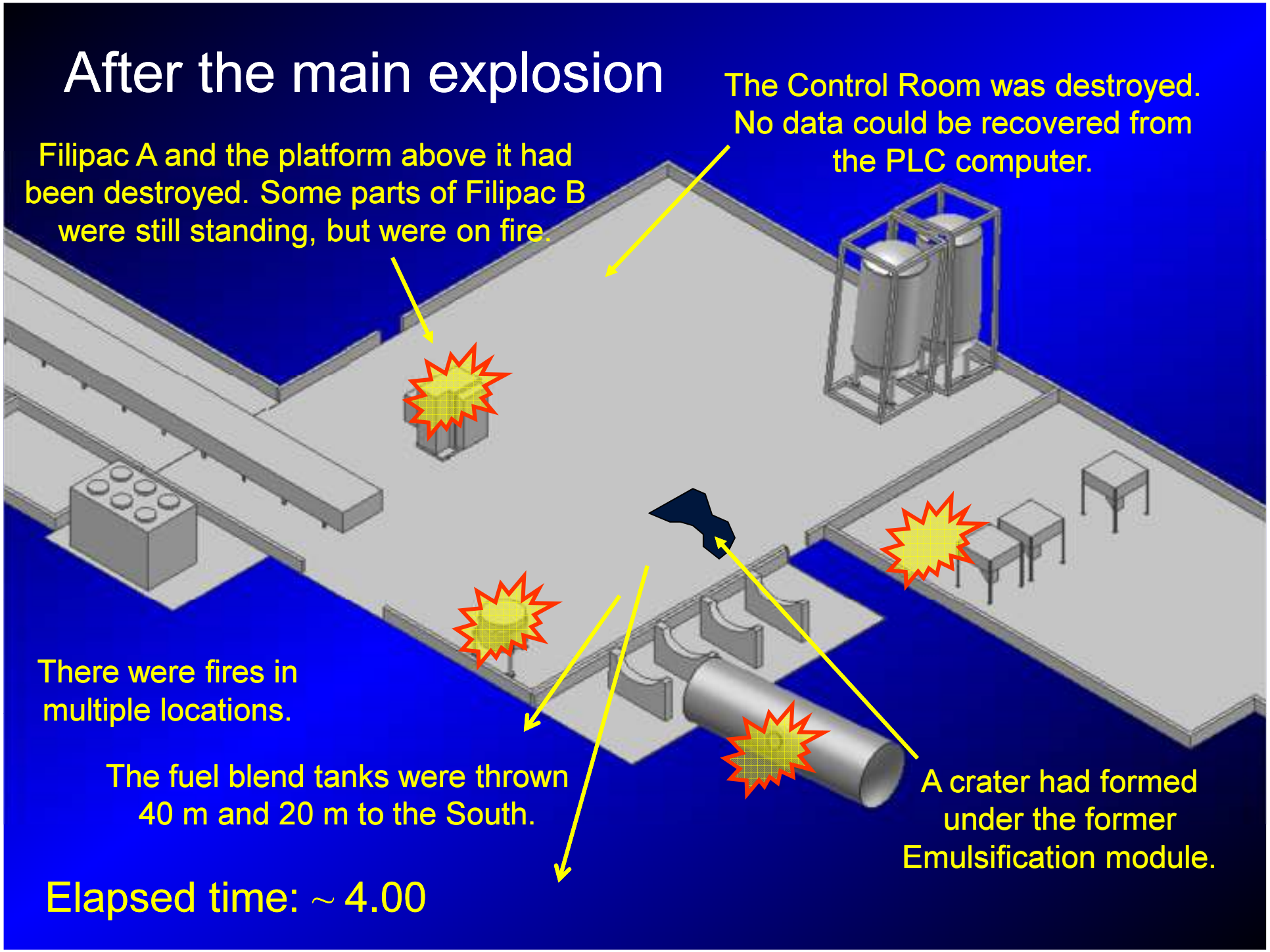
The injured operator had almost crawled to the main door.
He saw the Plant Supervisor and a colleague approaching.

Elapsed time: ~ 3:44

The main explosion



After the main explosion



The third intermediate explosion

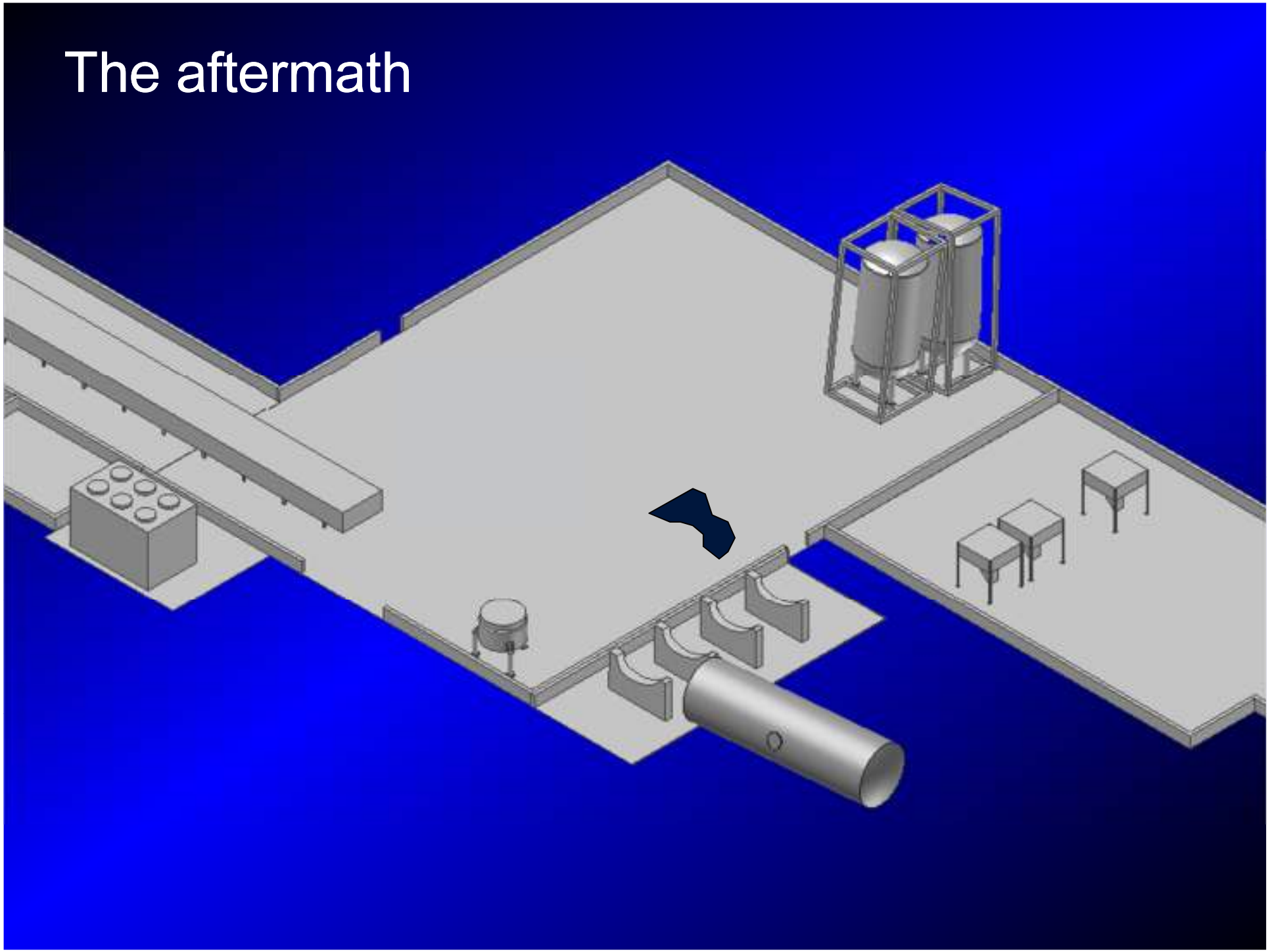
After burning for about 15 minutes, the remains of Filipac B exploded.

The fireball was photographed from a position about 400 m to the North East.

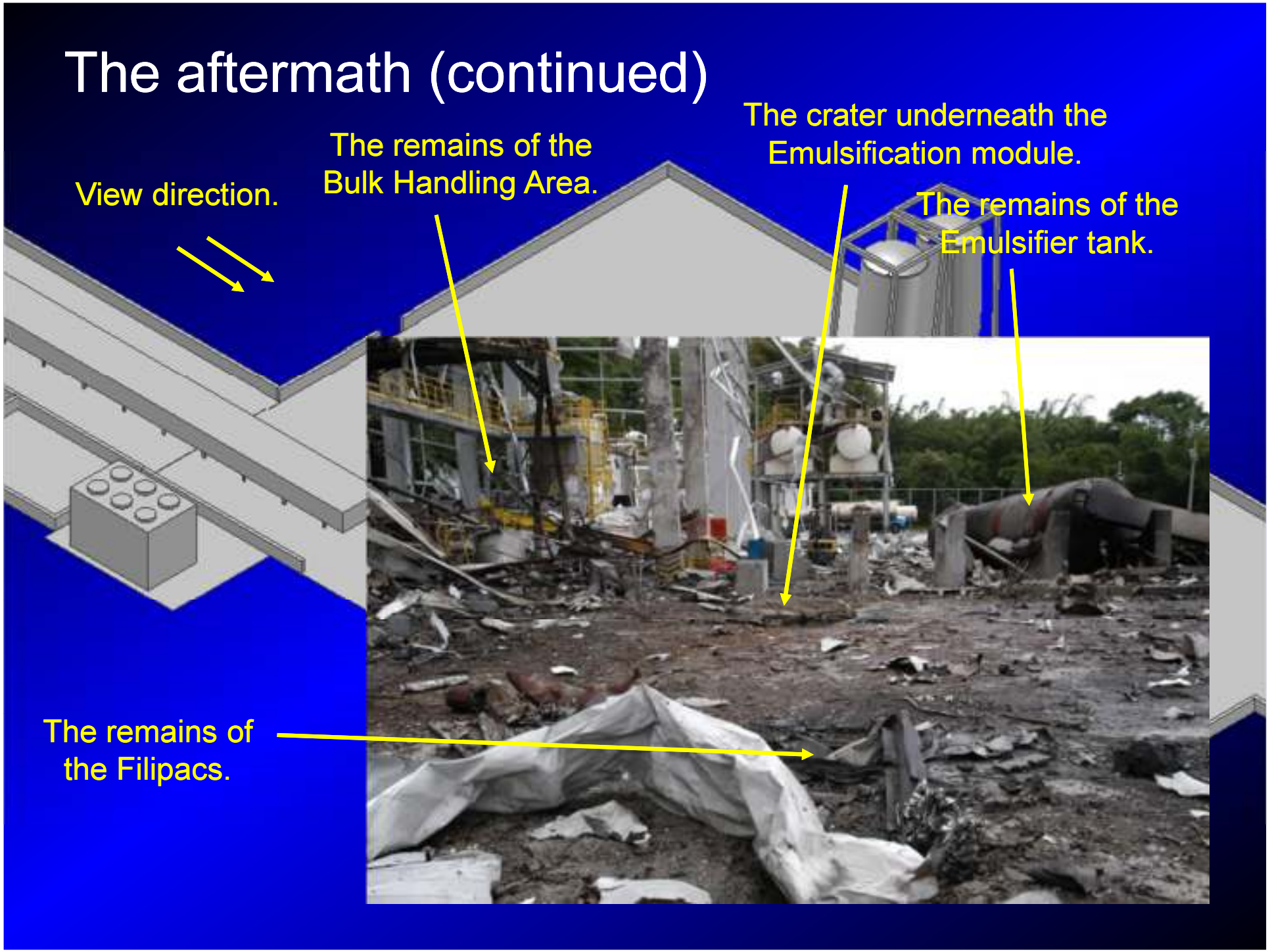
There was a further injury when someone giving medical assistance was startled, and bumped against some sharp debris.

Elapsed time: ~ 19.00

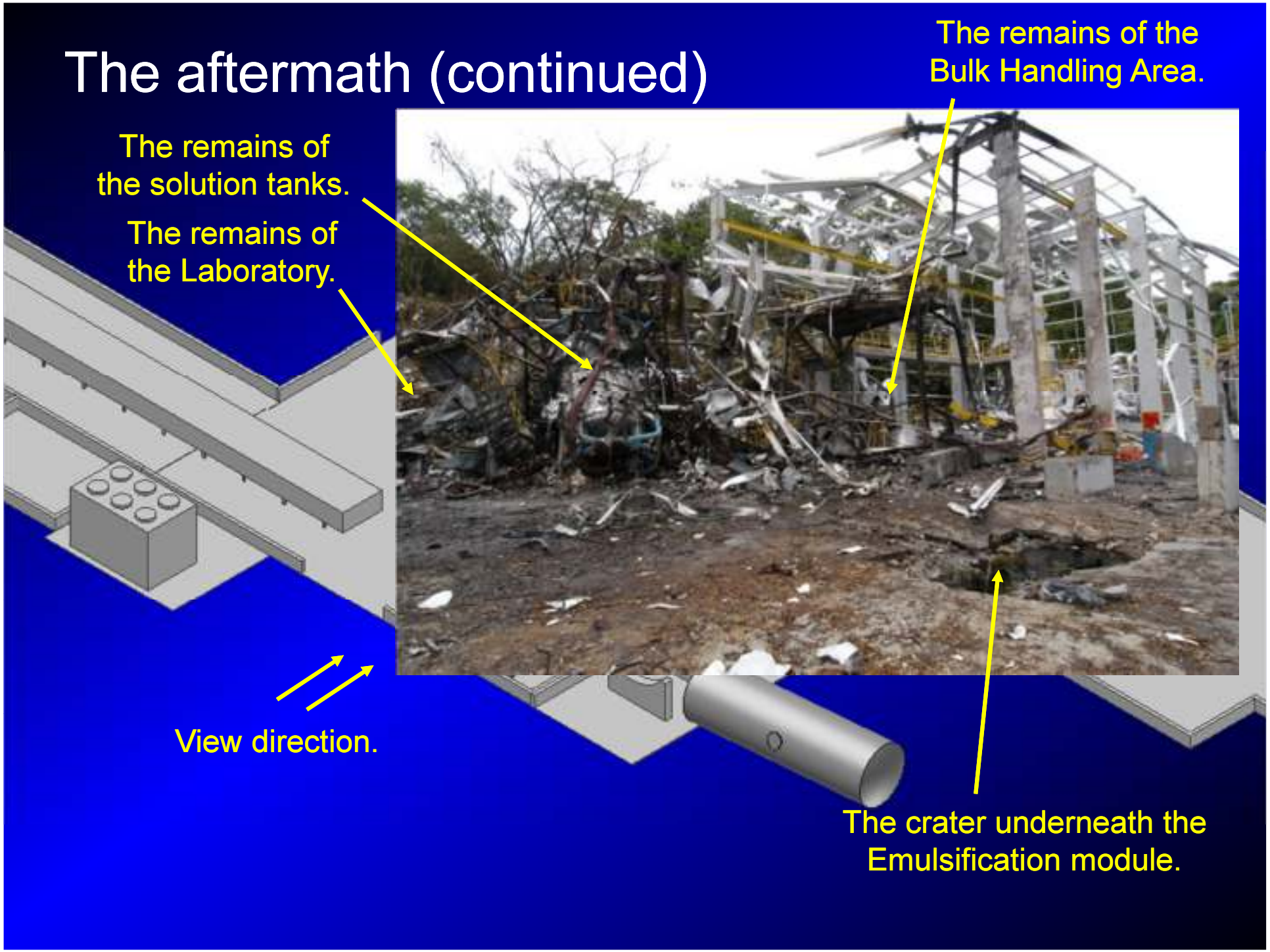
The aftermath



The aftermath (continued)

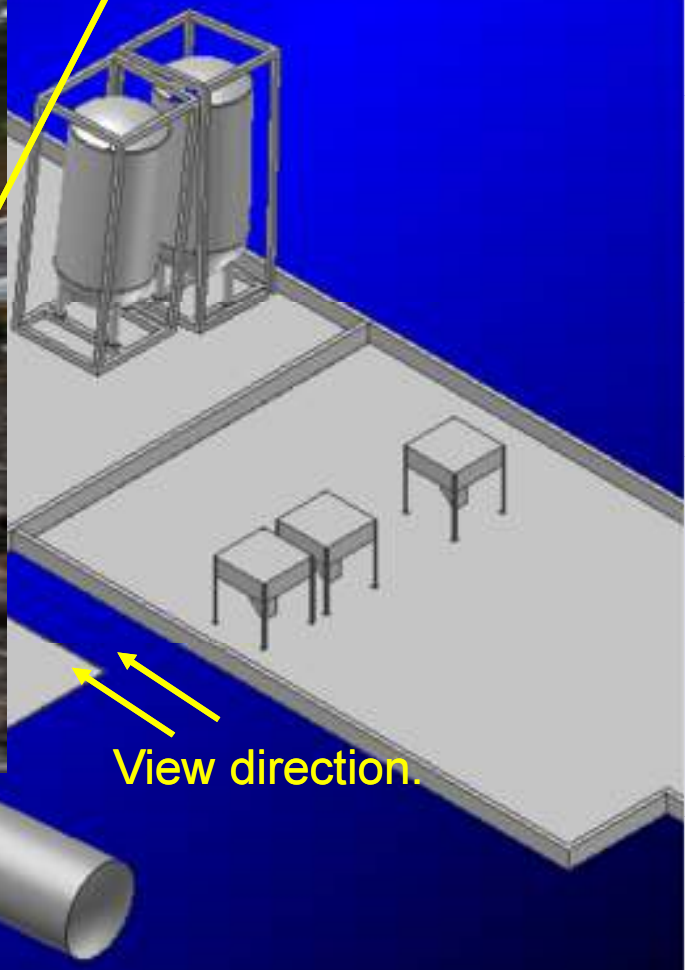


The aftermath (continued)



The aftermath (continued)

The remains of the Control Room.



View direction.

The remains of the Cooling Bath corridor.

The remains of the Filipacs.

The aftermath

The remains of the Cooling Bath corridor.

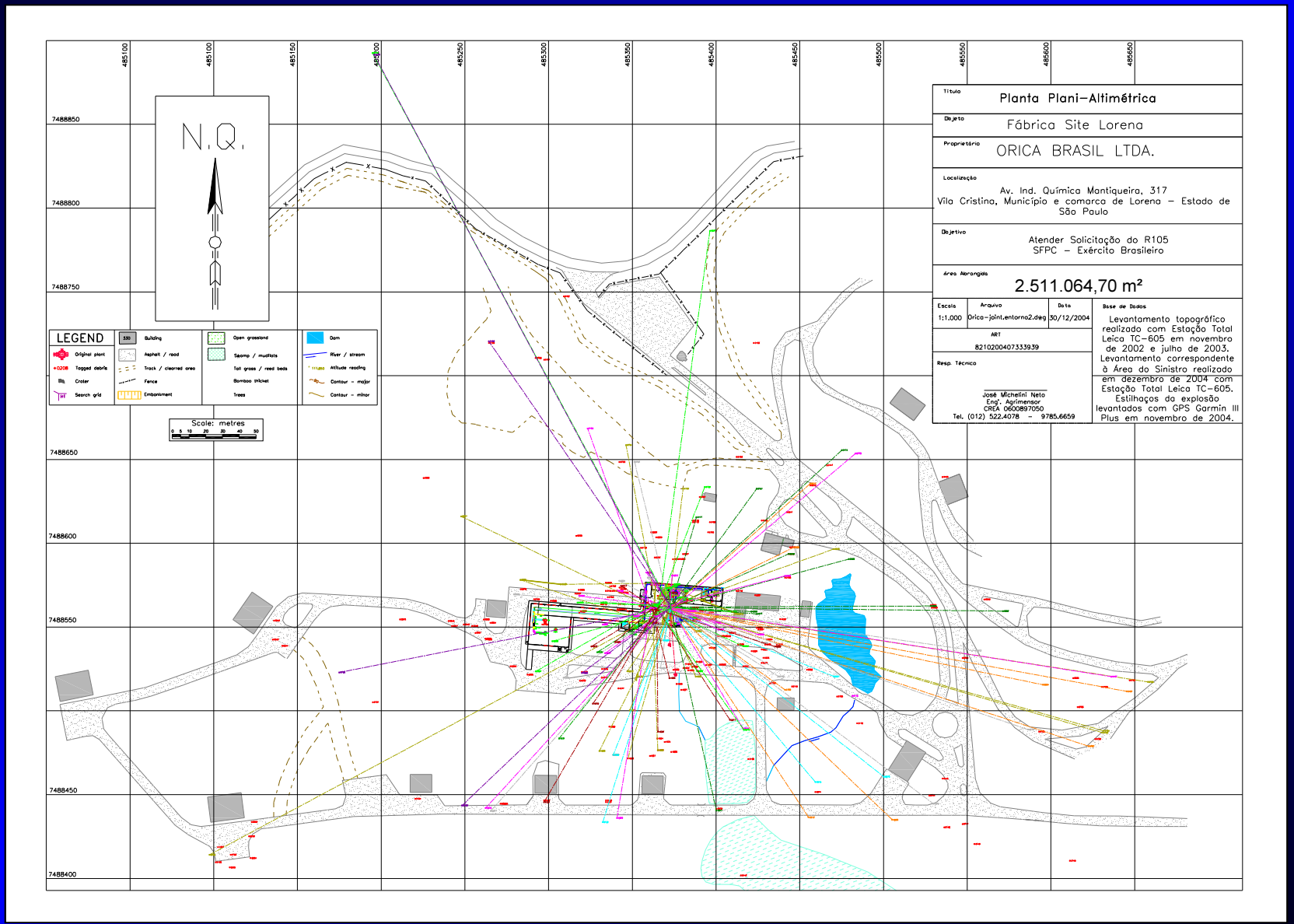
The remains of the Bulk Handling Area.

View direction.

Debris recovery and analysis

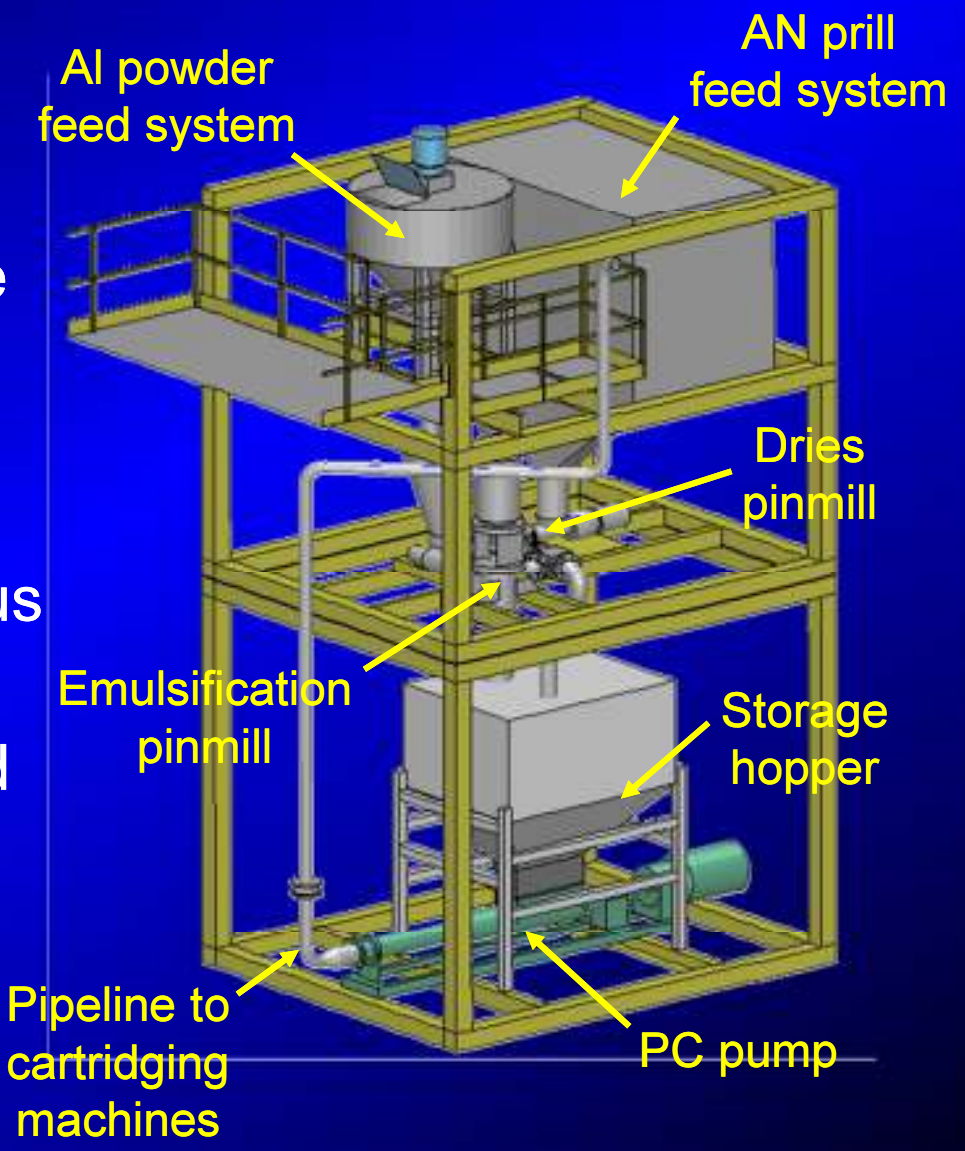
- Over 300 significant items of debris were surveyed, tagged and recovered. Each item was inspected for exposure to fire and to explosion.
- About 150 of these items could be identified positively, with their original location known.
- An individual debris distribution map was prepared for each of 20 significant process modules or sub-units.
- These maps indicated that there was one main explosion centre, and four secondary sympathetic initiation sites.
- Anomalies in the fire exposure and in the distribution maps established the consequences of the first small explosion prior to the main explosion.

Master debris distribution map



The Emulsification module

- Leading up to the event, AN/SN/SP solution + fuel blend were being fed into the Emulsification pinmill.
- The refined emulsion matrix was then blended with aluminium powder and porous AN prill in the Dries pinmill.
- The doped matrix was stored in an intermediate hopper before being pumped across to the cartridging machines.

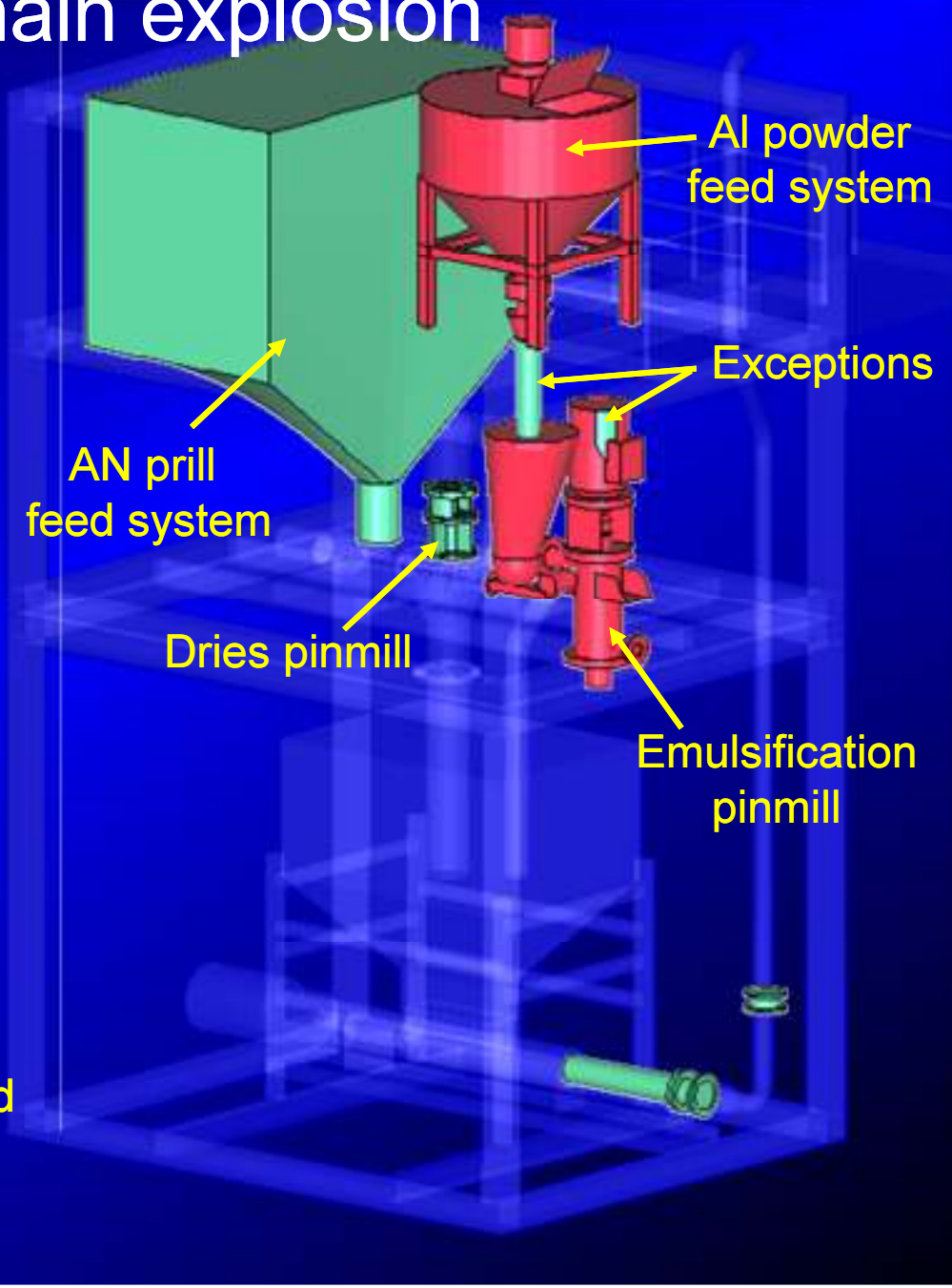


Possible initial event

- Steam cleaning or water ingress into Aluminium system
- Lumping of Aluminium and possible evolution of hydrogen from water/aluminium reaction
- Friction event in Aluminium metering augers
- Friction/heat ignited hydrogen/aluminium dust
- Dislodgement of aluminium system allowing loss of containment of aluminium causing fire

The fire prior to the main explosion

- The fire had engulfed
  - all of the aluminium powder feed system *except* for the connecting pipeline.
  - all of the Emulsification pinmill *except* for one fragment of its motor casing.



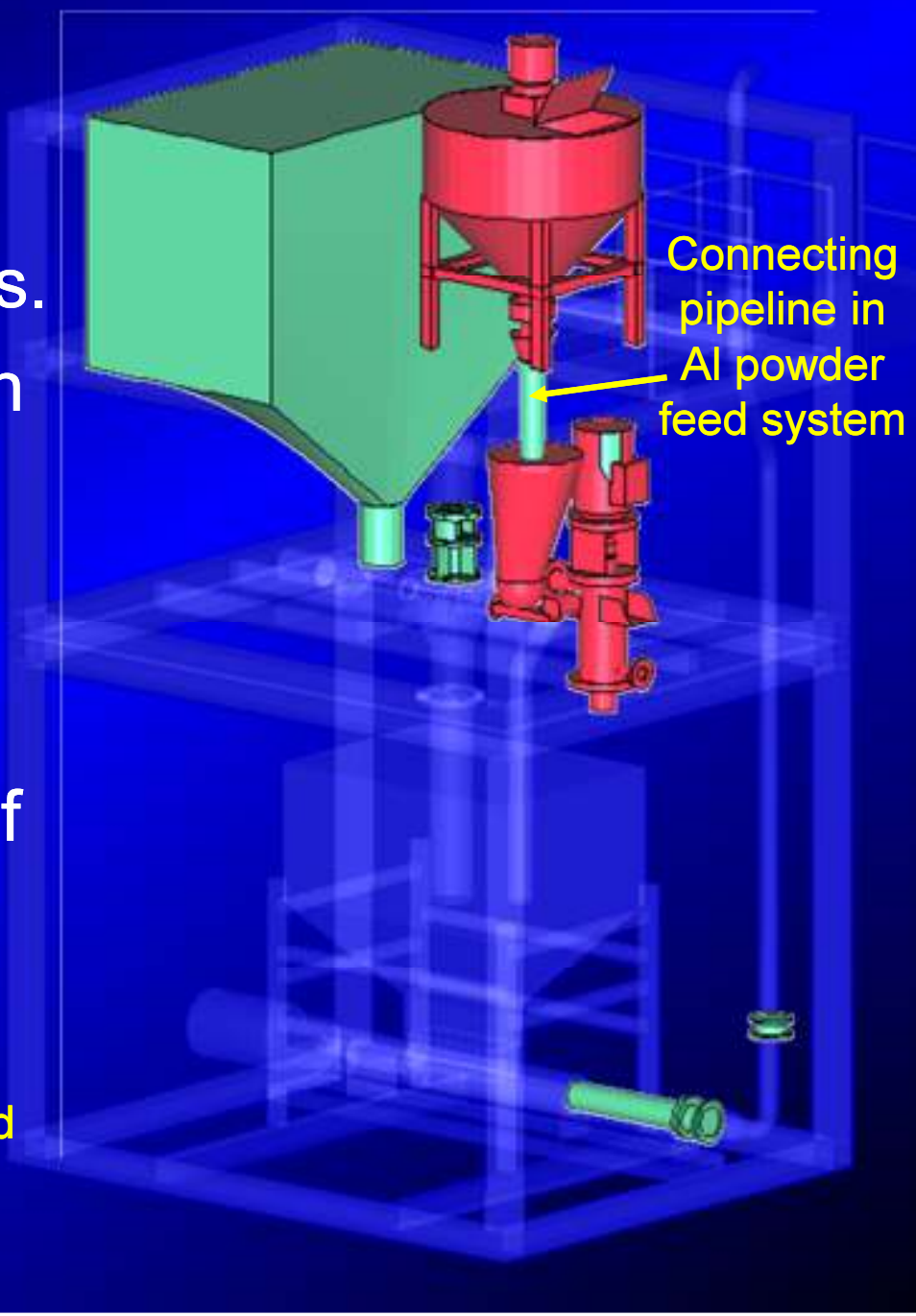
Known to be fire-affected

Known not to be fire-affected

Status uncertain

The exceptions

- These two exceptions showed other anomalies.
- The pipeline was thrown in the exact opposite direction to the rest of the items in the Al powder feed system. It had acquired traces of green paint.



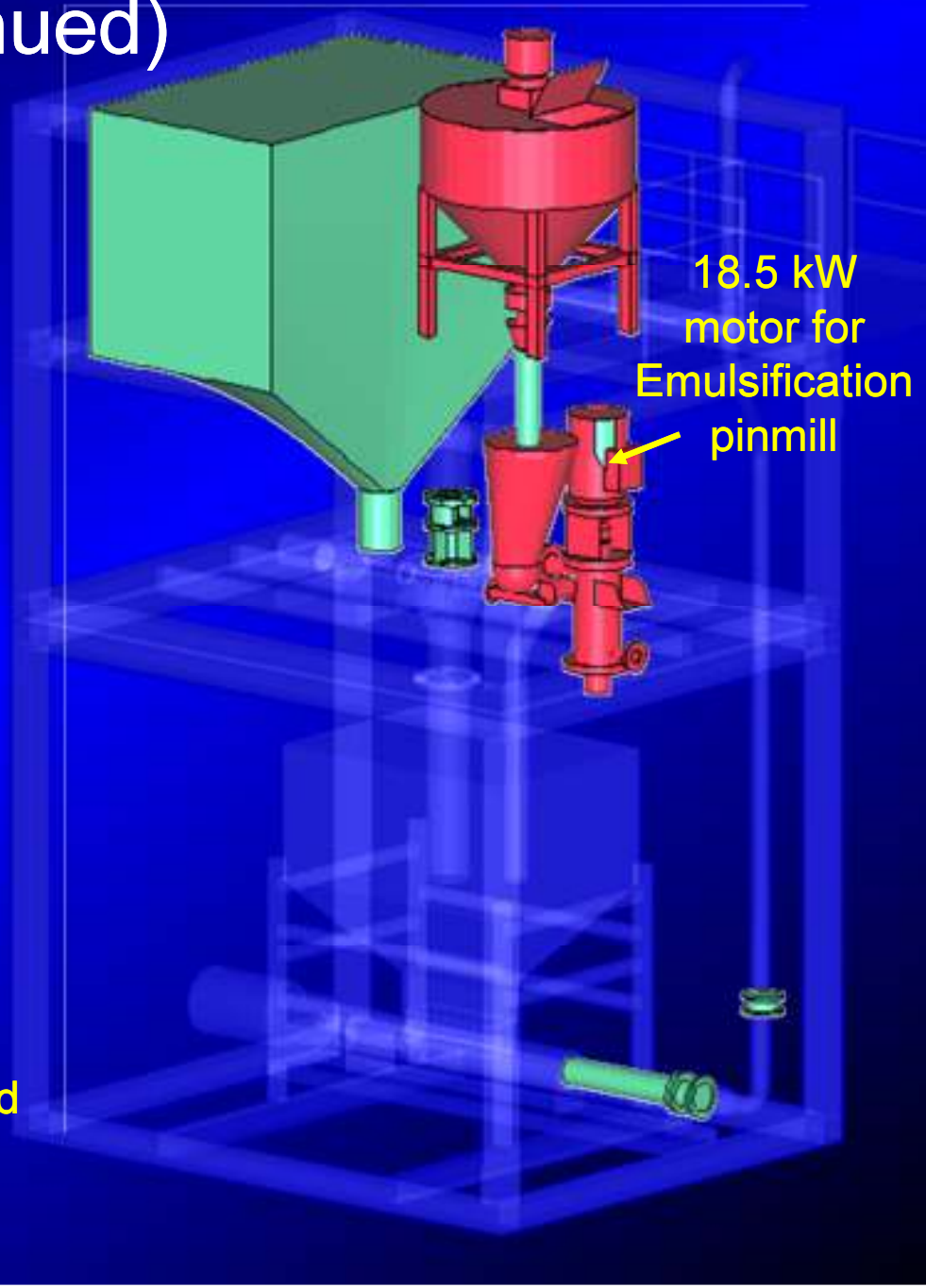
Known to be fire-affected

Known not to be fire-affected

Status uncertain

The exceptions (continued)

- The fragments of the 18.5 kW motor casing were scattered widely, being thrown as far as 225 m in all directions.



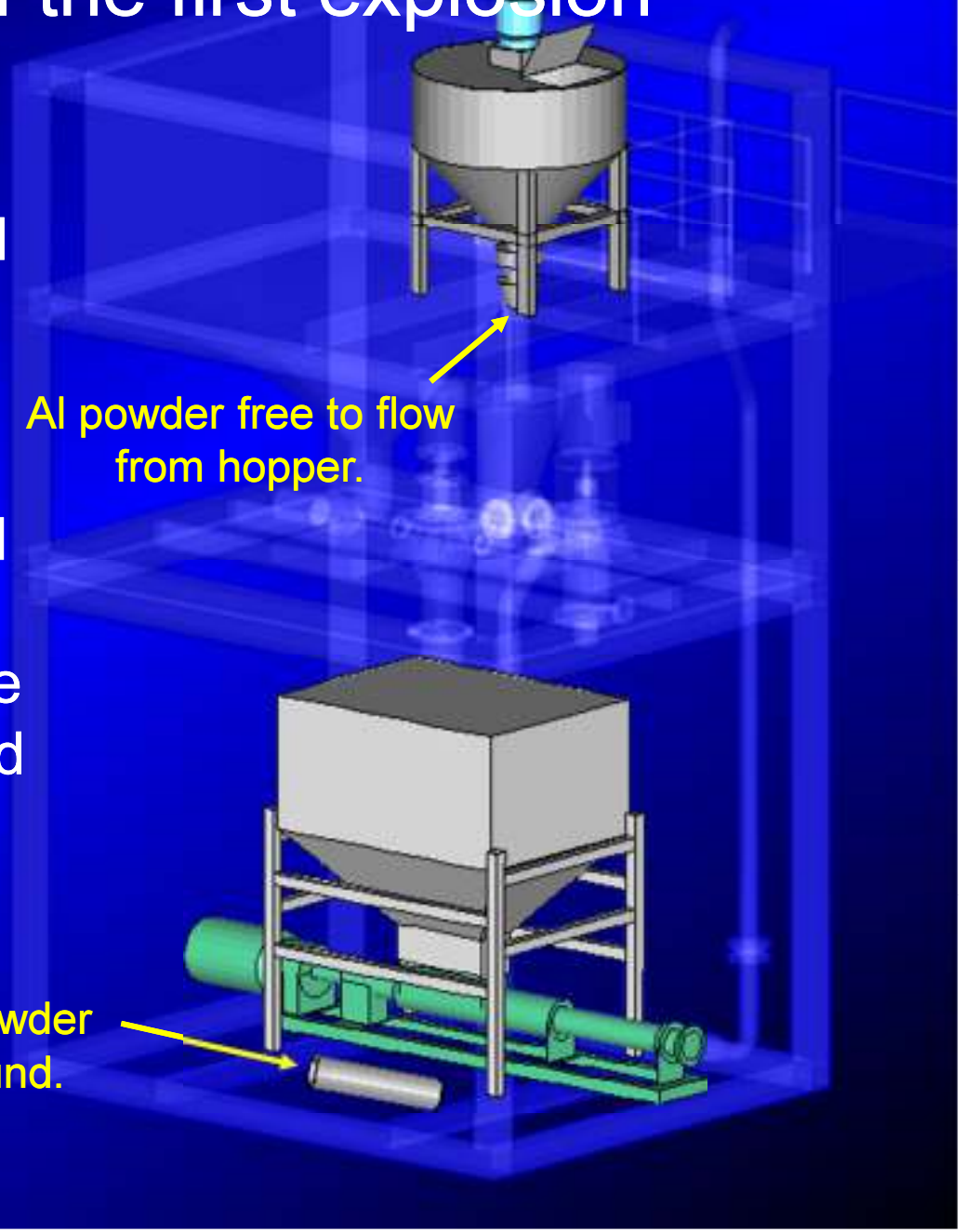
Known to be fire-affected

Known not to be fire-affected

Status uncertain

The consequences of the first explosion

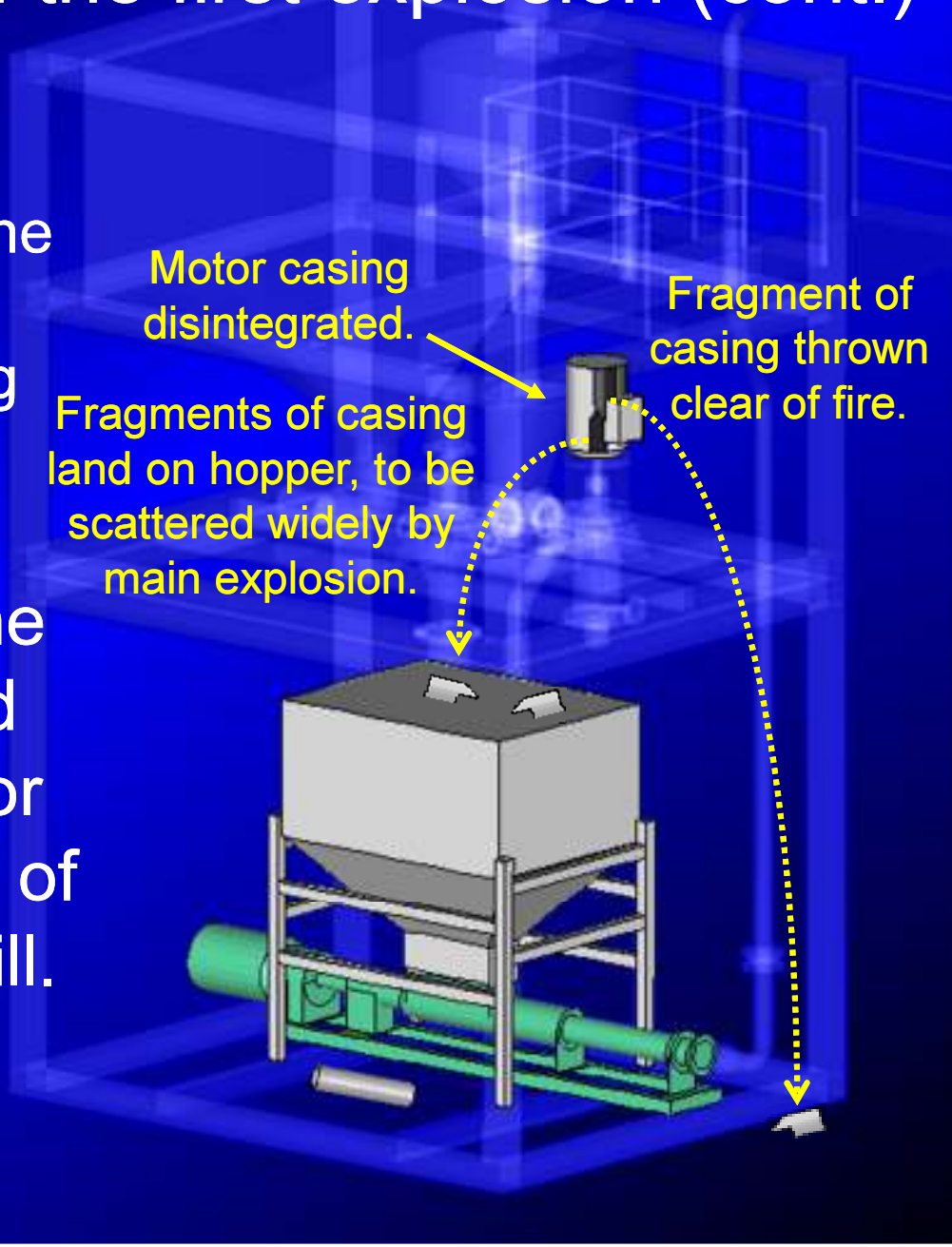
- It is inferred that:
  - The connecting pipe had fallen to the floor, and was lying next to the (green) PC pump.
  - Its dislodgement allowed aluminium powder to flood the area around the Emulsification pinmill and to fuel the subsequent fire.



Elapsed time: ~ 0:20

The consequences of the first explosion (cont.)

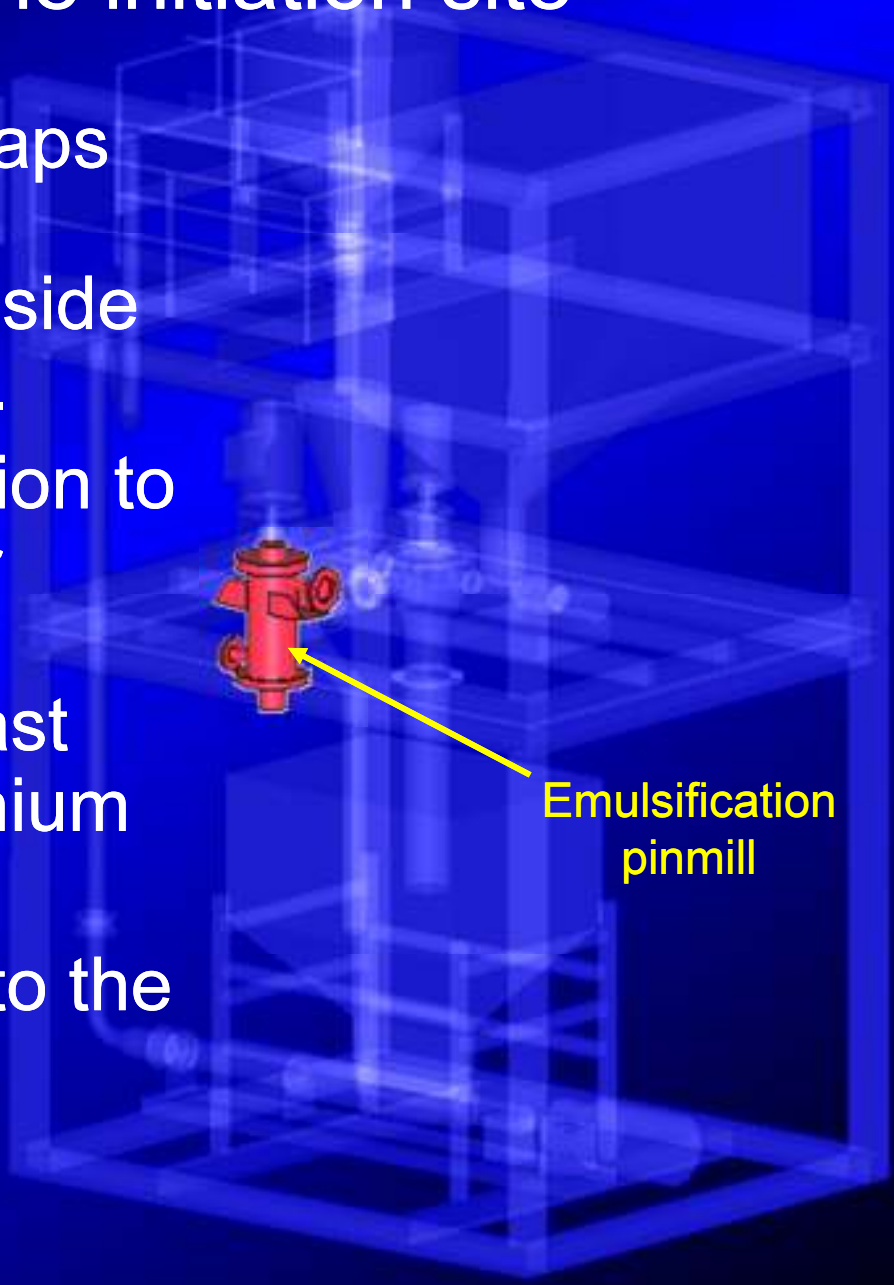
- It is inferred that:
  - The cast iron casing of the motor had disintegrated, and fragments were lying on top of the hopper and on the ground.
- It was concluded that the first small explosion had occurred either inside, or very close to, the motor of the Emulsification pinmill.
- .



Elapsed time: ~ 0:20

The main explosion: The initiation site

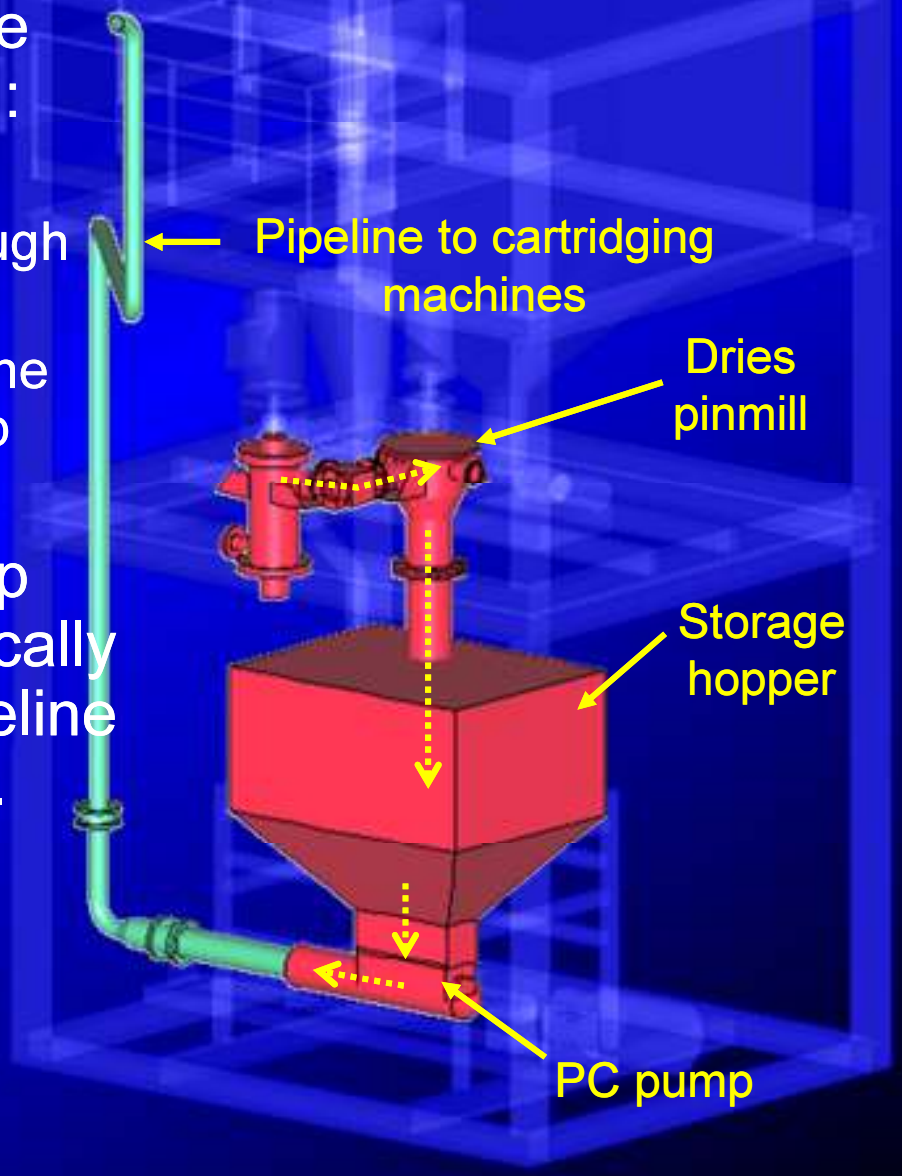
- The debris distribution maps indicated that the main explosion likely started inside the Emulsification pinmill.
- It is inferred that a transition to detonation occurred after about three minutes of engulfment in a fire at least partially fuelled by aluminium powder.
- The mechanism leading to the transition is not known.



Elapsed time: ~ 3:45

The main explosion: Propagating detonation

- The debris indicated that the detonation then propagated:
  - through the 3-way valve
  - into the top of and down through the Dries pinmill
  - through the hopper and into the inlet chamber of the PC pump
- The detonation did not propagate through the pump stator, nor did it sympathetically initiate the matrix in the pipeline to the cartridging machines.



Known to have detonated

Known to have not detonated

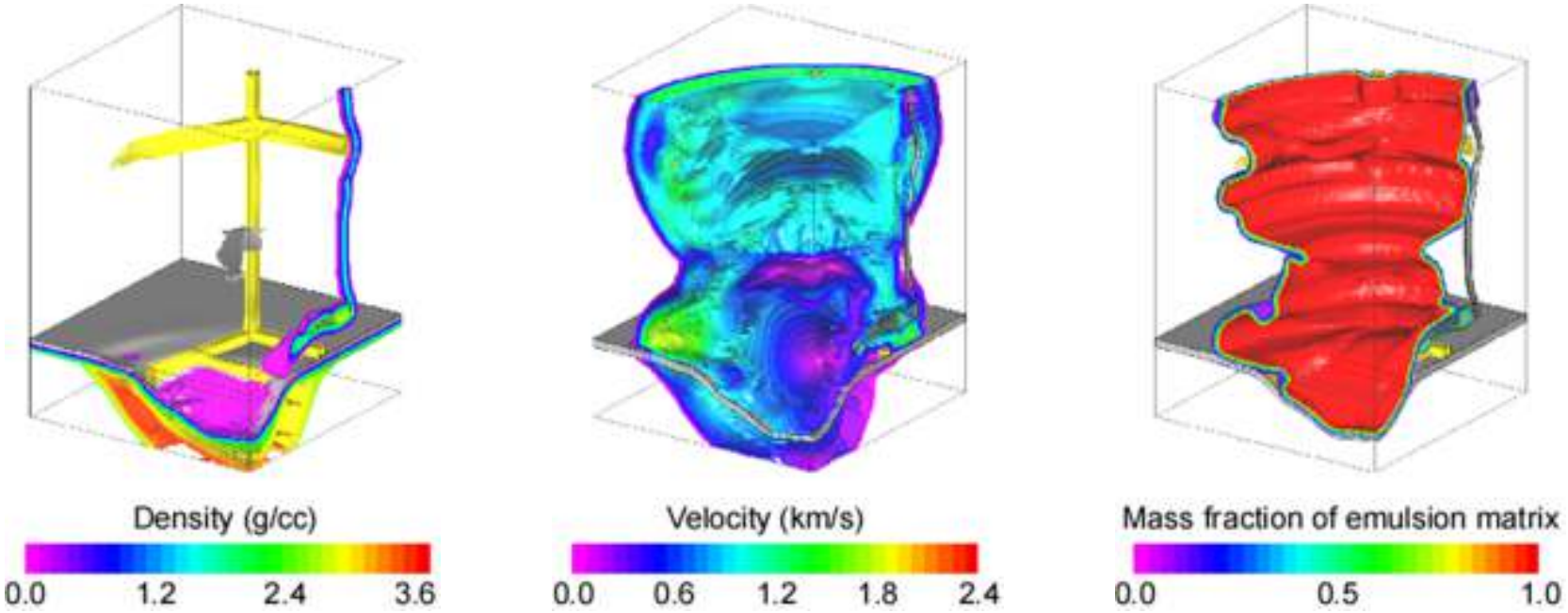
Not involved

Elapsed time: ~ 3:45

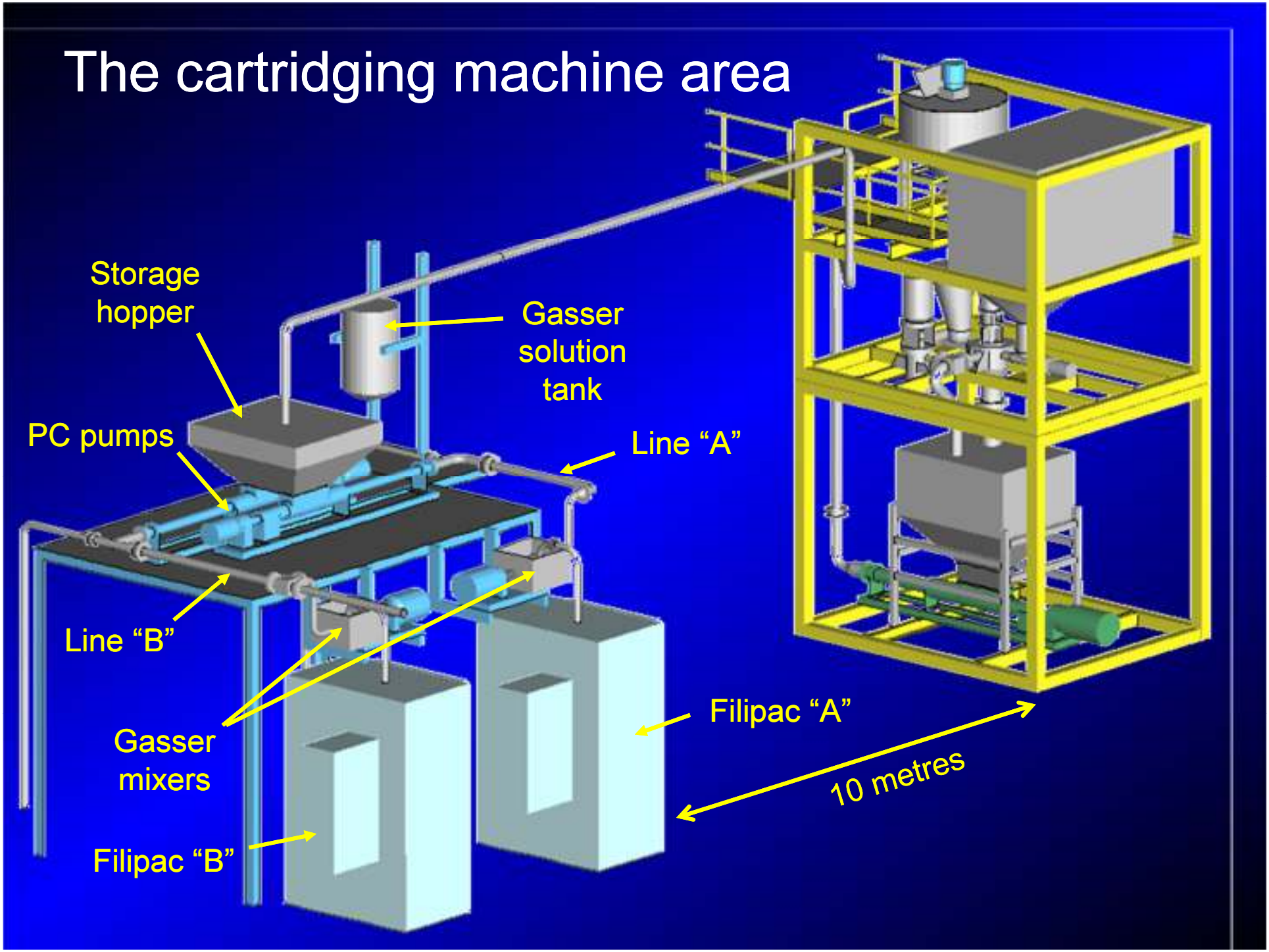
The main explosion: Estimate of yield

- The DFEM code LS-DYNA was used to simulate the explosion for different assumed masses of emulsion matrix in the emulsification module.

Quarter-space model with symmetry planes through PC pump and hopper, shown 1.5 milliseconds after initiation of 200 kg emulsion matrix.



The cartridging machine area



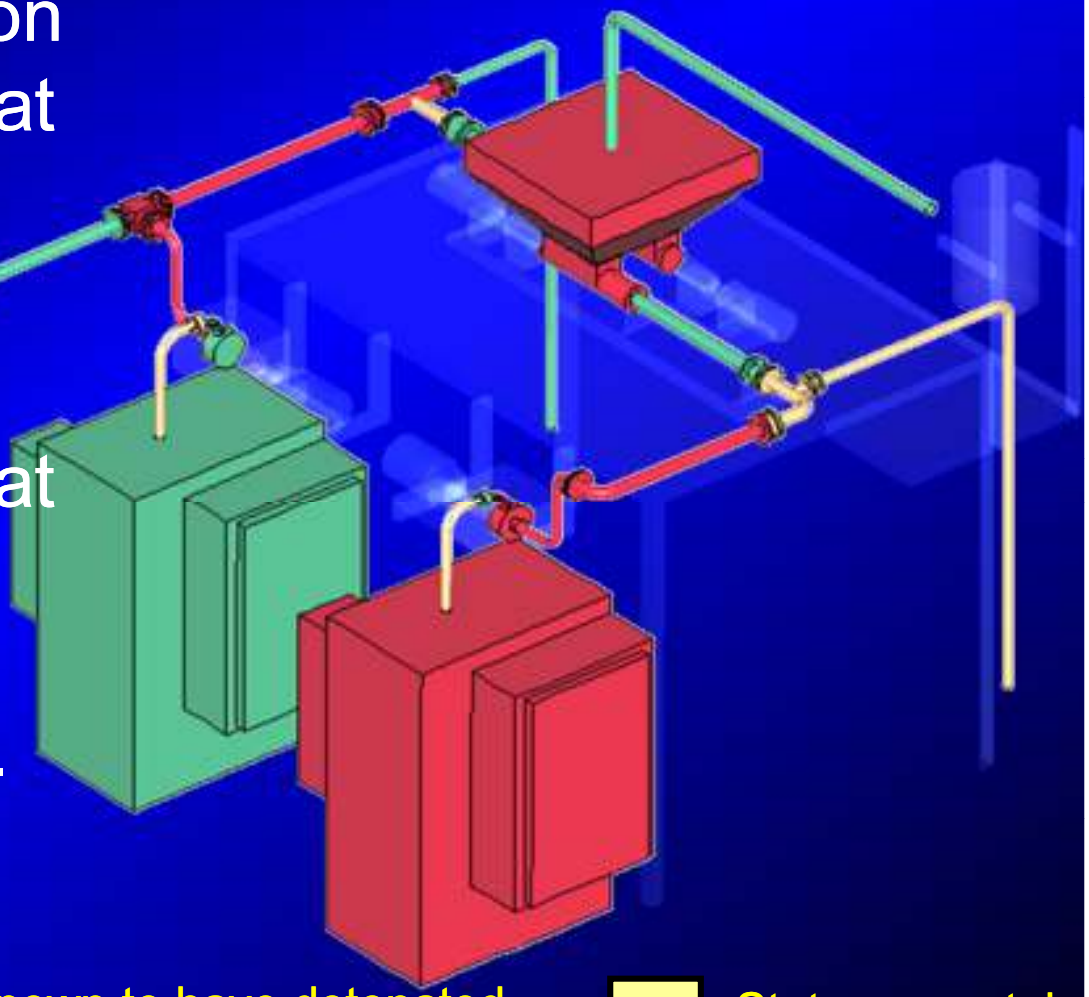
The main explosion: The cartridging machines

- The witness statements established that Filipac A and the associated platform and matrix hopper were destroyed during the main explosion.
- Filipac B was still in position after the main explosion, though on fire. (It was destroyed in the third, lesser explosion 15 minutes later.)

Elapsed time: ~ 3:45

The main explosion: The cartridging machines

- The debris distribution maps established that several detonations had occurred in this region.
- However, regions that had detonated were interspersed with regions that had not.



Known to have detonated

Known to have not detonated

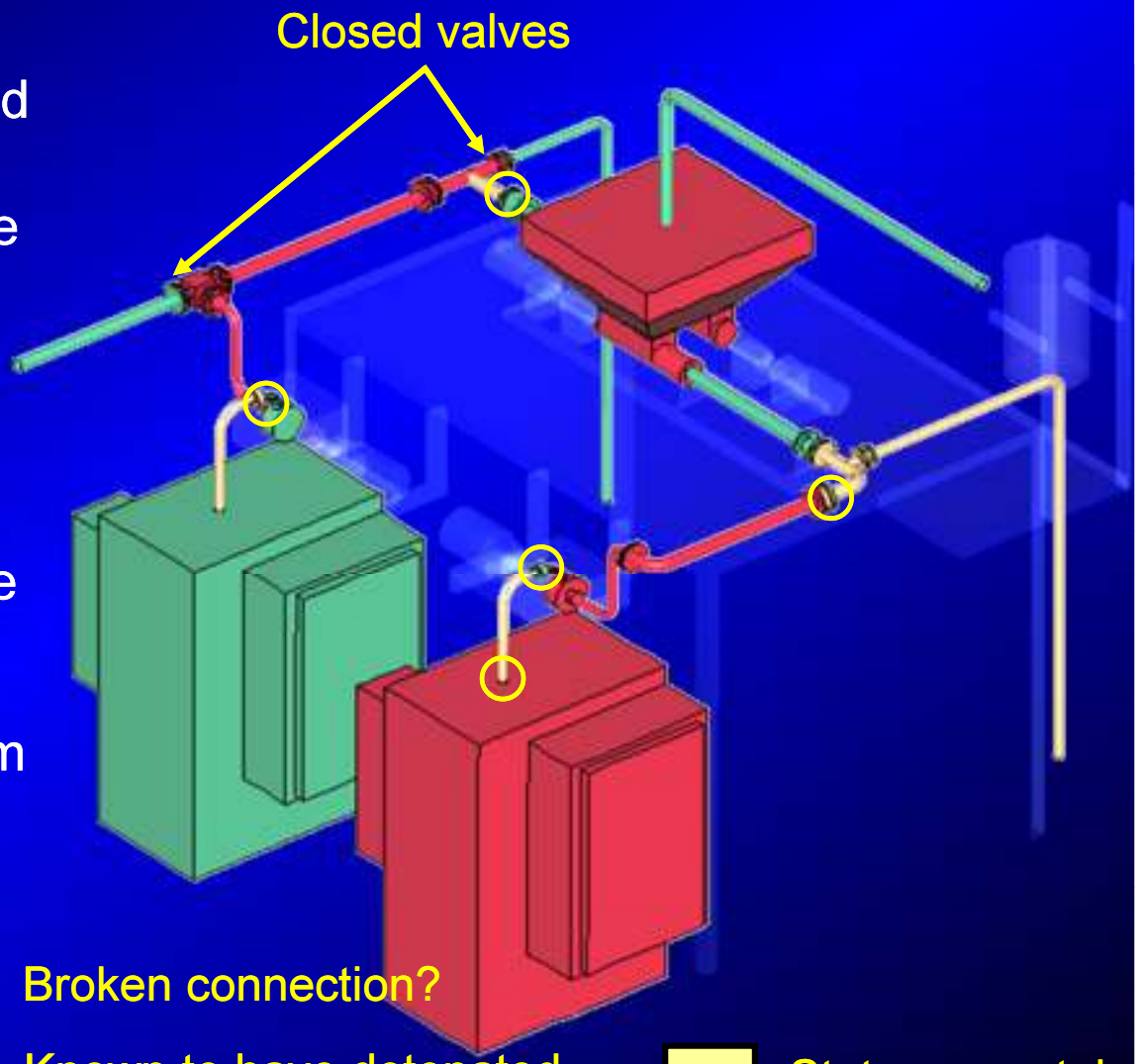
Status uncertain

Not involved

Elapsed time: ~ 3:45

The main explosion: The cartridging machines

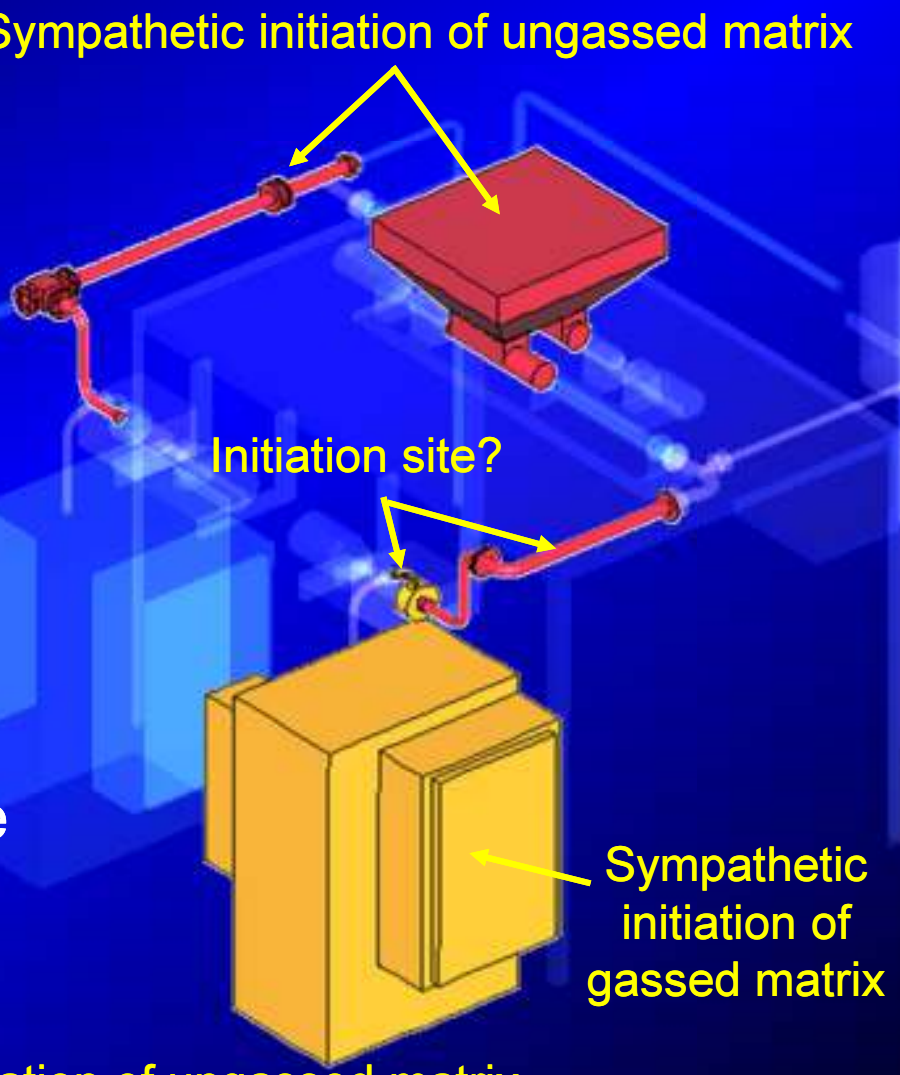
- Two of these interruptions were obviously due to closed valves.
- It is inferred that some of the connections must have broken prior to the onset of each sympathetic initiation, and undergone relative displacement.
- This means there must have been a time delay (of about 10 ms or so) between the arrival of the blast wave from the emulsification module and the onset of initiation at each site.



Elapsed time: ~ 3:45

The main explosion: The cartridging machines

- There were four separate sympathetic initiation sites:
  - The sympathetic initiation in Filipac A involved *gassed* matrix.
  - At least two of the sympathetic initiations involved *ungassed* matrix, namely in the hopper and in Line B.
  - The fourth site combined ungassed matrix in Line A and gassed matrix in Votator A.
- The time delays between the initiations are not known.



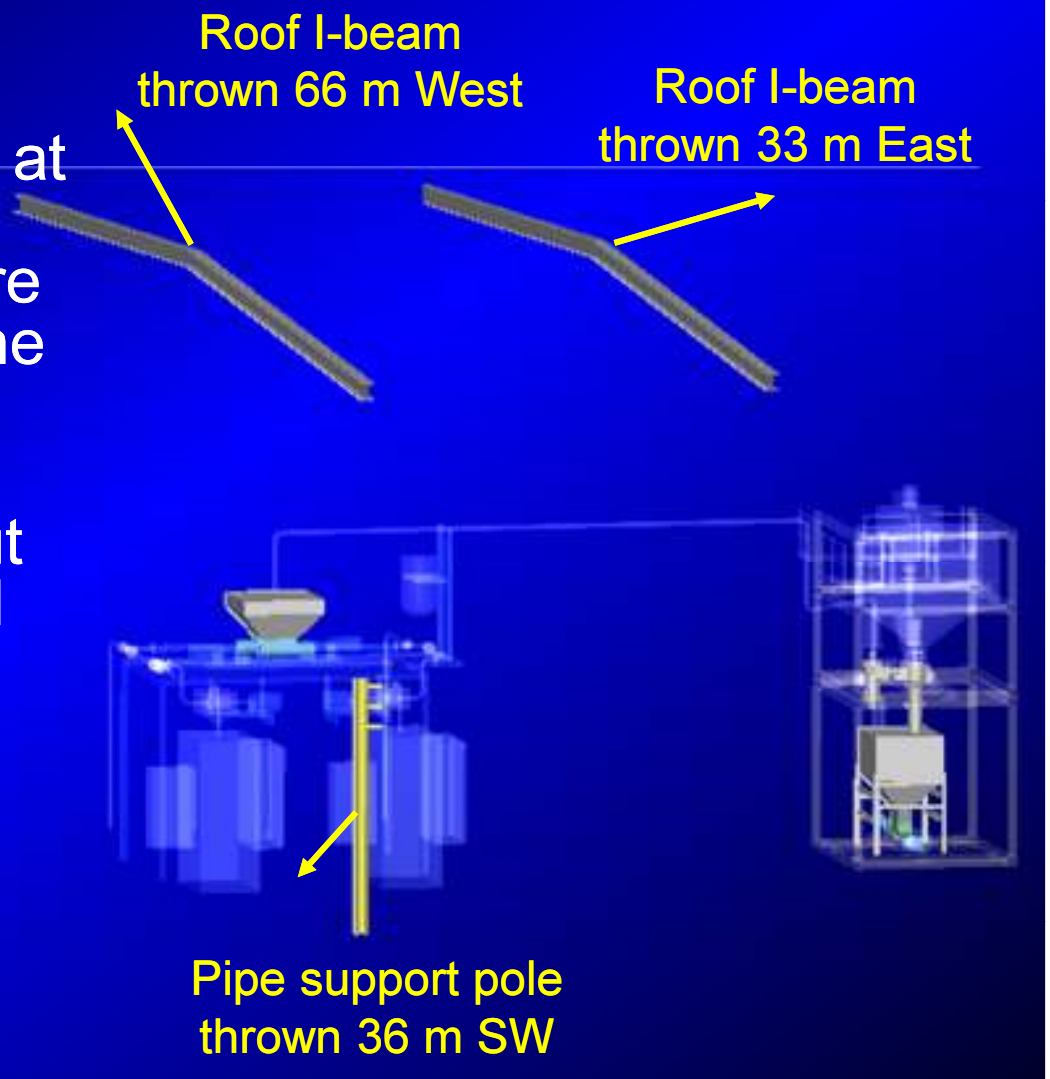
Detonation of ungassed matrix

Detonation of gassed matrix

Elapsed time: ~ 3:45

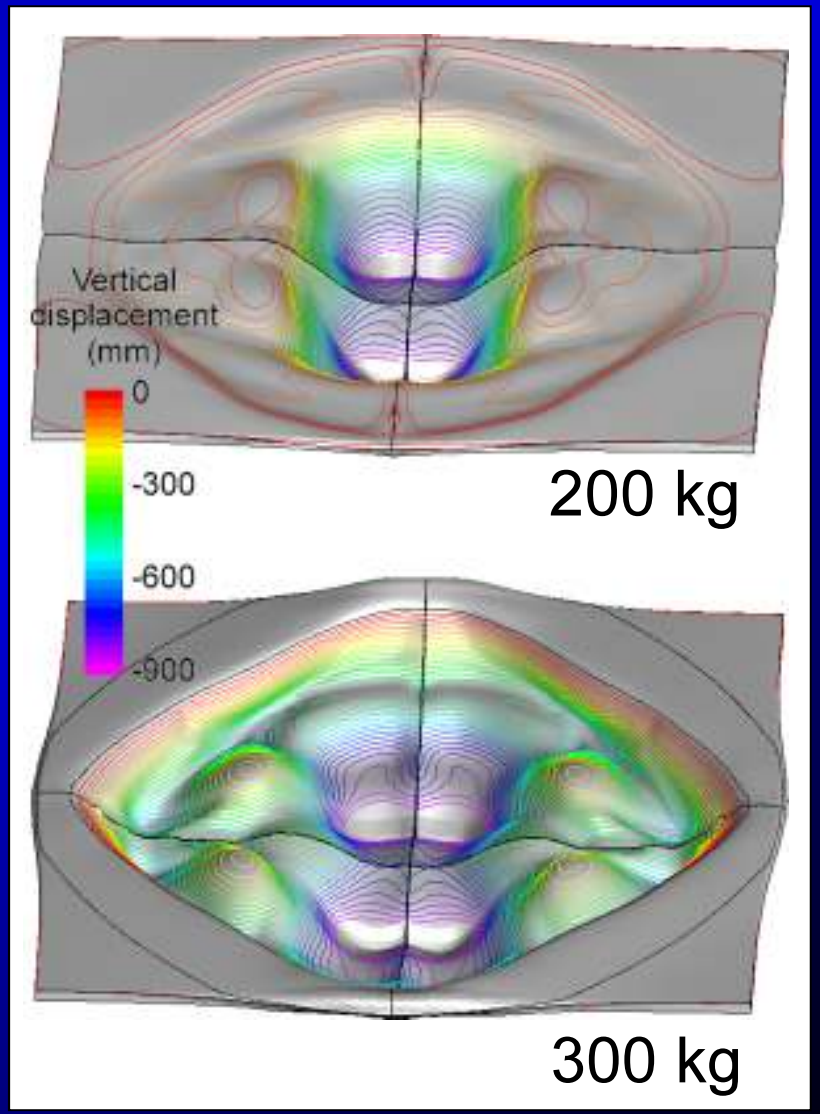
The cartridging machines area: Estimate of yield

- The relative contributions from the explosion centres at the Emulsification module and above the Filipacs were determined by analysing the throw directions of several structural items.
- It was concluded that about 25% more matrix exploded above the Filipacs than at the Emulsification module.
- Since the latter was previously estimated to be about 200 kg, the former was estimated to be about 250 kg.



The main explosion: Estimate of yield (cont.)

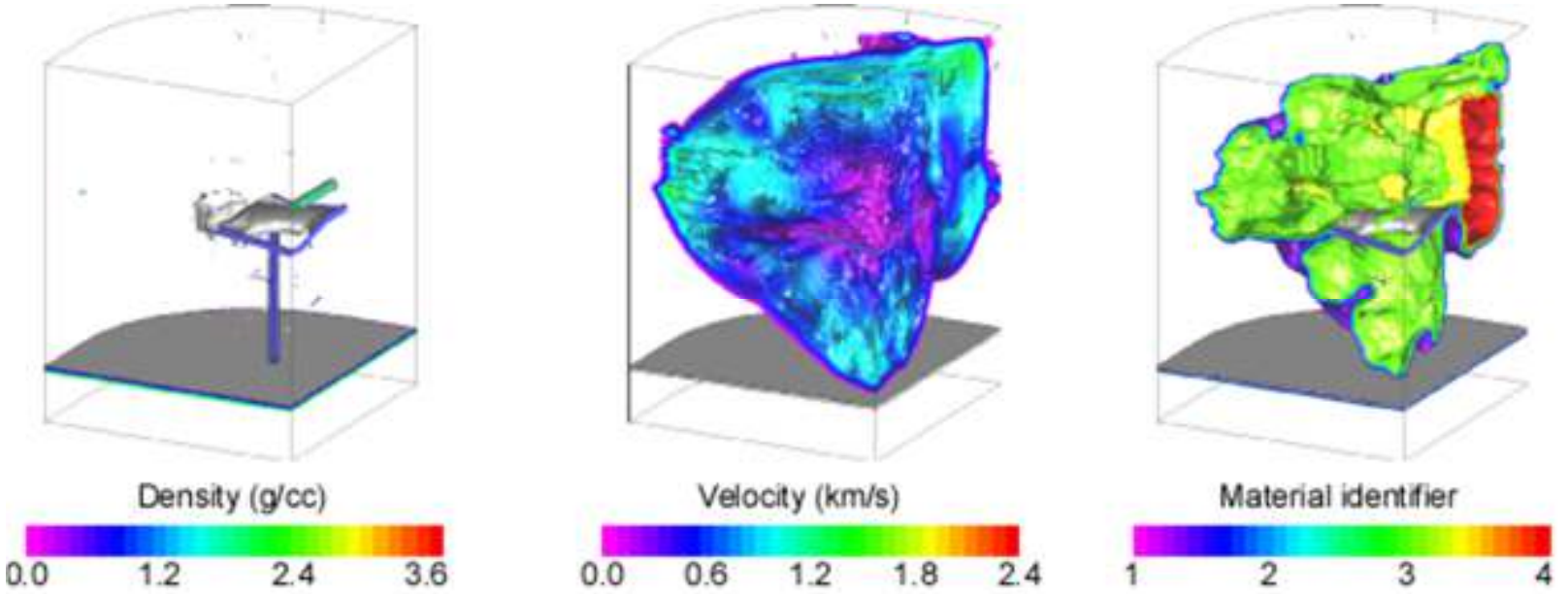
- The best simulated match to the size and shape of the crater under the Emulsification module was for an assumed explosion of 200 kg emulsion matrix.



Estimate of yield: Verification

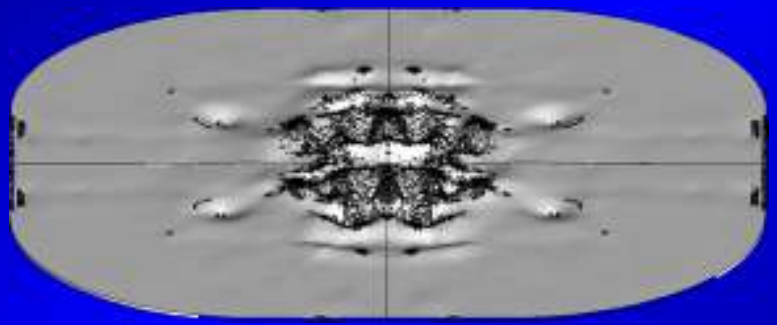
- The DFEM code LS-DYNA was used to simulate the explosions above the Filipac machines for different assumed masses of emulsion matrix and for different delay times between the assumed initiation sites.

Quarter-space model with symmetry planes through hopper, shown 2.5 milliseconds after initiation in the hopper and sympathetic initiation in the Gasser mixer.



Estimate of yield: Verification (continued)

- The simulations were inconclusive, indicating that the blast wave had been too weak to fracture the concrete floor, but that the observed damage was most likely due to shrapnel impact and penetration.
- The order of the separate sympathetic initiations could not be determined.

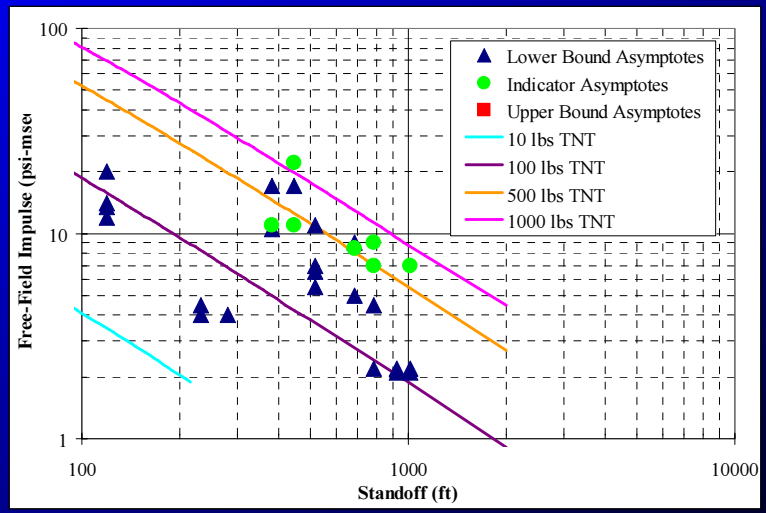


Simulated crater

Filipacs area during salvage

Estimate of total yield

- Baker Engineering and Risk Consultants, Inc., analysed the blast-induced damage to surrounding buildings.
- They estimated a total explosion yield of 270 kg TNT equivalent, corresponding to an explosion yield from about 360 kg AN-based explosive.
- This is in reasonable agreement with the 450 kg total derived by the independent analysis of crater formation and throw of structural items.



Summary: The event

- The event escalated through a series of fires and explosions.
- The cause and site of the initial fireball and fire have not been precisely identified, but occurred somewhere inside the Emulsification module.
- The site of the first small explosion about 15 seconds later has been localised to either within or next to the cast iron frame of the 18.5 kW motor driving the Emulsification pinmill.
- The initiation site of the main explosion about 3 minutes later has been identified as most likely inside the Emulsification pinmill. The exact mechanism leading to detonation has not been determined.
- The detonation propagated through the rest of the matrix inventory in the Emulsification module, stopping at the stator of the PC pump. The explosion involved about 200 kg emulsion matrix to this stage.
- Four separate sympathetic detonations occurred in the hopper and the pipelines above the Filipac cartridging machines. These explosions involved a further 250 kg emulsion matrix.
- A final explosion destroyed the remains of a Filipac machine that had been on fire for about 15 minutes.

ROOT CAUSES

Fire in the emulsion module led to 3 explosions

Fatalities due to inappropriate evacuation

Extent of damage due to process inventory and proximity of equipment

Summary: The consequences

- 3 people fatally injured.
- 7 other people injured, including two requiring partial amputations.
- Main plant building destroyed.
- Extensive damage to surrounding area.
- Debris scattered to 375 m.

Recommendations

People

- Prepare and implement a plan for emergency drills
  - to be completed monthly
  - integrated with site-wide drill annually
- Train all supervisors in hazard awareness and identification techniques.
- Provide refresher training to all operators in the relevant Basis of Safety for their operation.
- Carry out a comprehensive review of all critical procedures through job cycle checks by supervisors.

Recommendations

Technology

- Set up a Design Review Panel for Bulk, Packaged, IS, and AN Technologies to:
  - set mandatory standards on Technology for manufacture
  - review designs of new plants against these standards
  - carry out SHE and operability reviews at new and existing plants
- Formalise group-wide design philosophy and fundamental requirements and parameters; update with respect to:
  - intra-plant and inter-plant separations
  - inventory levels and blast protection

Recommendations

For all operations there need to be systems in place to ensure that everyone in their operation is :

- mindful of the potential hazards that our processes and materials can cause if appropriate controls are not in place
- in compliance with the company core safety systems:
  - Change management
  - Risk assessments
  - Unusual Occurrence reporting and resolution
- diligent in closing out audit and incident actions in a timely manner

Recommendations

- fully aware of inherent process safety (Basis of Safety) of their processes and the materials they handle
- maintaining standards, with any non-conformances detected, investigated and corrected
- aware of emergency response requirements
  - emergency alarms and their location
  - panic stops and their location
  - initial communication requirements
  - the emergency response training needed, and
  - the drills required
- clear on what is acceptable behaviour with respect to evacuation procedures