Unmanned Surface Vehicle for Spent Nuclear Fuel Inspection

Nuclear robot and diagnosis team

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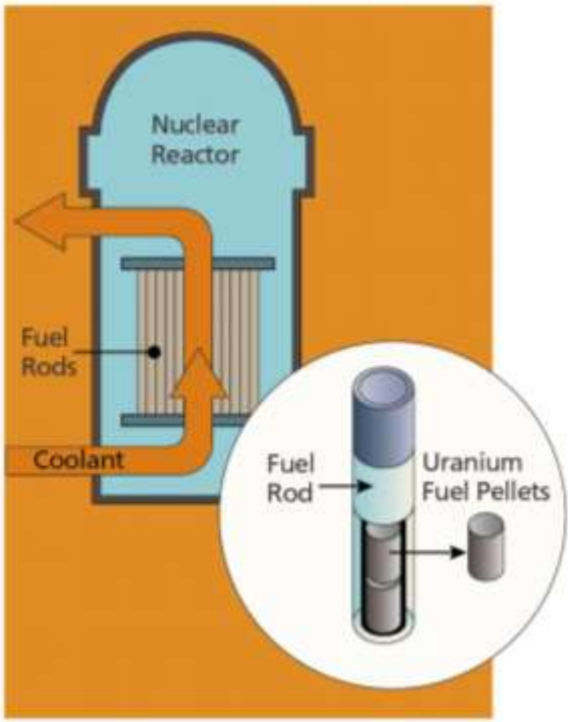
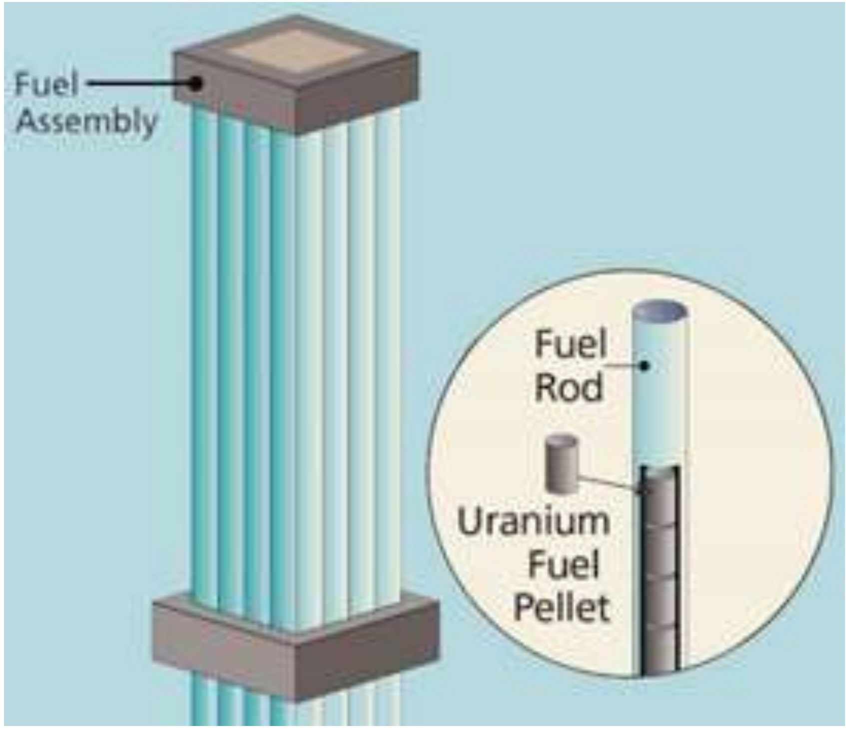
Spent nuclear fuel

Nuclear Fuel



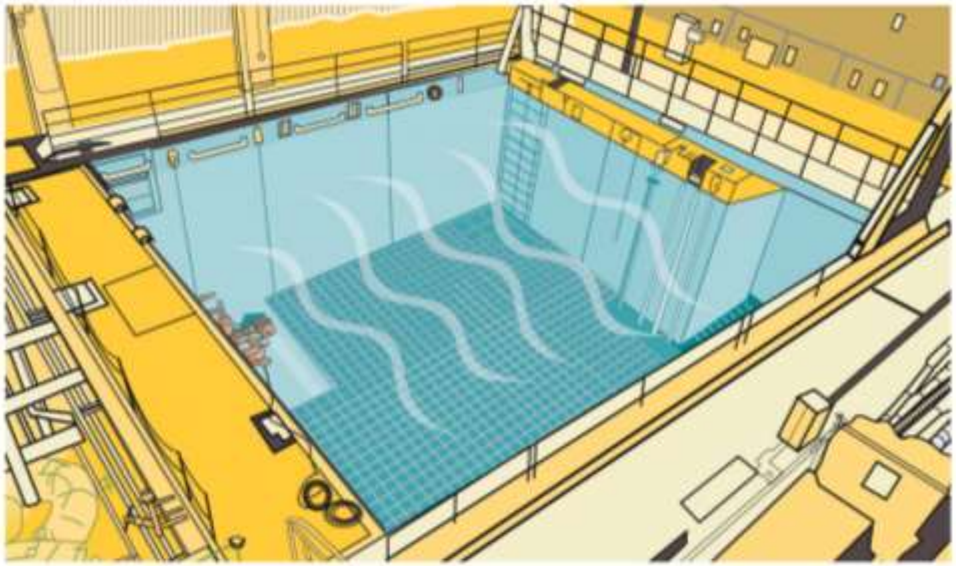
Spent Nuclear Fuel

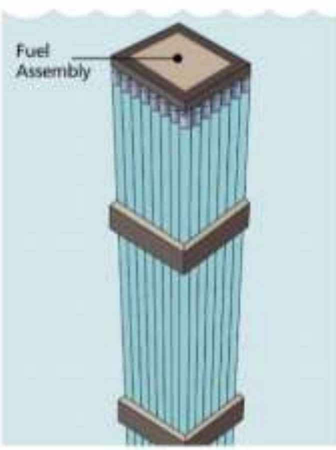


- Bundles of uranium pellets encased in metal rods that have been used
- produces a lot of radiation and heat
- must be managed to protect workers, the environment and the public

https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/storage-spent-fuel.html

Spent fuel pool





2 After 5–6 years, spent fuel assemblies—typically 14 feet (4.3 meters) long and containing nearly 200 fuel rods for PWRs and 80–100 fuel rods for BWRs—are removed from the reactor and allowed to cool in storage pools for a few years. At this point, the 900-pound (409-kilogram) assemblies contain only about one-fifth the original amount of uranium-235.

- Size
  - Pool depth: 12 m
  - Fuel height: 4.3 m
- Are inside the plant's protected area.
- water to cool the fuel and provide radiation shielding
- Have no drains
- Have large safety margins: 20 feet of water above the fuel
- Robust: very thick, steel-reinforced concrete walls and stainless steel liners.
- May be located below ground level, shielded by other structures, or surrounded by walls that would protect the pool from a plane crash or other impact.

https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/storage-spent-fuel.html

Current spent fuel inspection

- Inspectors on the bridge
- handheld optical instrument, Improved Cerenkov Viewing Device (ICVD)
- to confirm the presence of spent fuel stored underwater (Yes/no)
- Check the strength of the Cherenkov light
- Random inspection
- Very slow process
- Hand writing, no image/video recording
- 1 time in a year

ICVD in a configuration with 250mm lens and an example of digital back

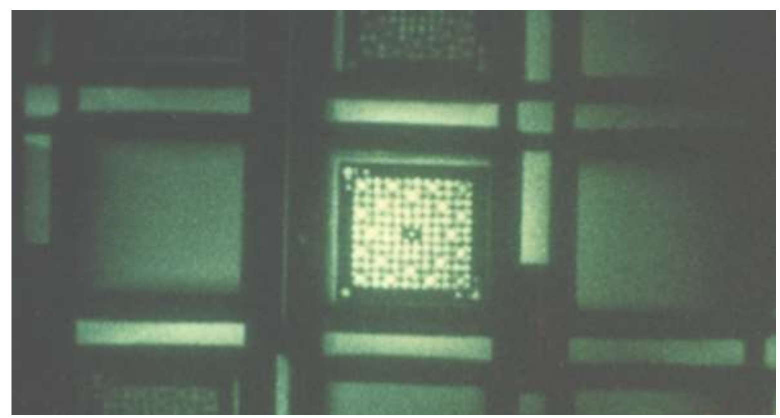


Illustration of what the ICVD would record through the underwater observation window

IAEA safeguards

IAEA

International Atomic Energy Agency

IAEA

- IAEA is to deter the proliferation of nuclear weapons

Department of Safeguards

- The Department of Safeguards carries out the IAEA's duties and responsibilities as the world's nuclear inspectorate, supporting global efforts to stop the spread of nuclear weapons

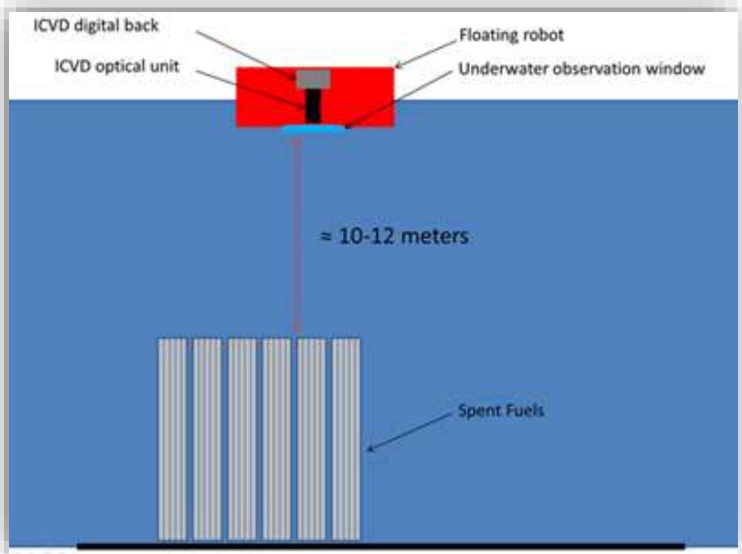
Division of Technical and Scientific Services

- The Division provides scientific and technical support to the Divisions of Operations. This includes the design, development, testing, calibration, installation and maintenance of safeguards equipment; performance and contamination monitoring of equipment; and inspection logistics.

IAEA Robotics Challenge

What do we want to improve?

- IAEA inspectors involve making repetitive measurements in areas that can be difficult to access, or with elevated radiation levels.
- This is a domain where robotic could play a role,
  - improve the working conditions of the inspectors
  - enhance the consistency of the IAEA measurements



Unmanned Surface Vehicle (USV)

- The IAEA would like to mount ICVD inside a small robotized floating platform, which would autonomously propel itself across the surface of the pond, while stabilizing the ICVD in a vertical position.

Challenge Roadmap

17.5 17.8 17.11 17.11.19~30

Submission of Deliverables

- Participants’ technical proposals
- Technical Evaluation 1

Demonstration Week

- 1 week of real-life tests in Australia
- Technical Evaluation 2

Proof-of-concept

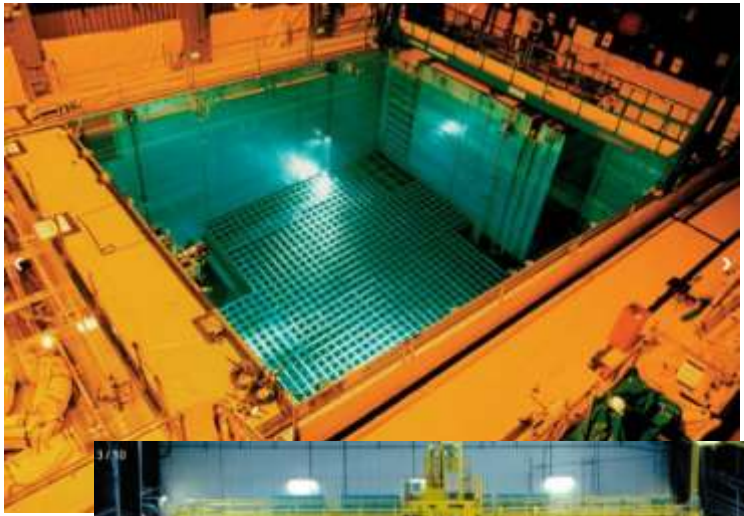
- Field deployment by IAEA inspectors
- Technical Evaluation 3

Procurement

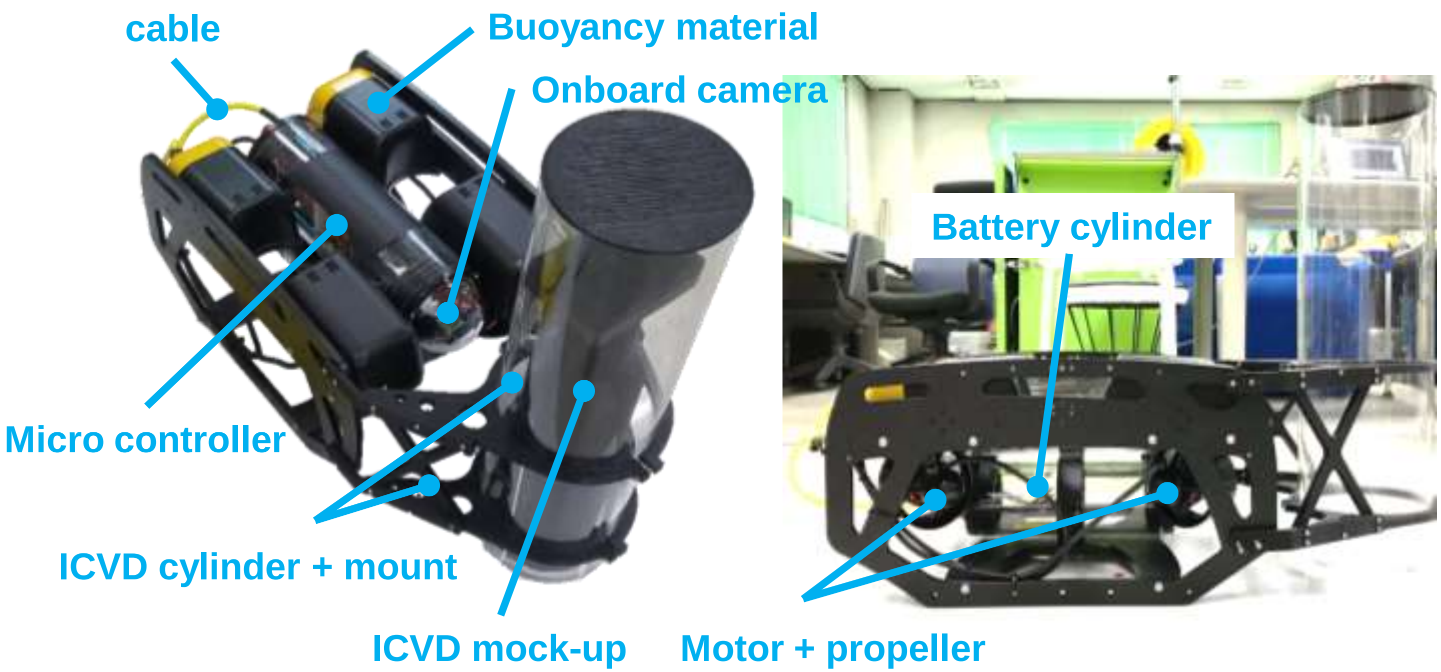
- IAEA Request for Proposal
- Financial Evaluation
- Contract Award to selected participants

USV requirements

- S1 : always remains buoyant, no part fall and the camera remains protected from water.
- S2 : camera remains stable and vertical
  - images are sharp at 1/10s exposure taken with a 250mm lens
  - account small waves
- S3 : carried in a plane, prepared by a single user.
- S4 : easily cleaned up and any trace of contaminated water
  - prevent the propelling system from spraying any potentially contaminated water
- S5 : autonomously guide within a few centimeters accuracy, and propel itself without any user input.
  - No external guiding infrastructure is allowed.
  - system for moderate circulation streams generated by water pumps.
  - follow straight lines, systematically scanning the fuel assemblies.



SCV (Spent fuel Check Vehicle)



- Four buoyant materials are located at the top
- ICVD mount and cylinder are located in front of the USV
- The microcontroller is inside the upper cylinder
- USV is completely waterproof
- 11.1 kg , can be easily handled by one person
- Four propellers for maneuvering the USV forward/backward, left/right and CW/CCW rotations
- Onboard camera for recognizing surrounding environment and spent fuel assemblies
- Power supply: lithium polymer battery, 14.8 V, 18000mAh
- Endurance: 5 hours
- Speed: 20 cm/sec
- Range: 50 meters (can be extended)

Control environment

Control environment

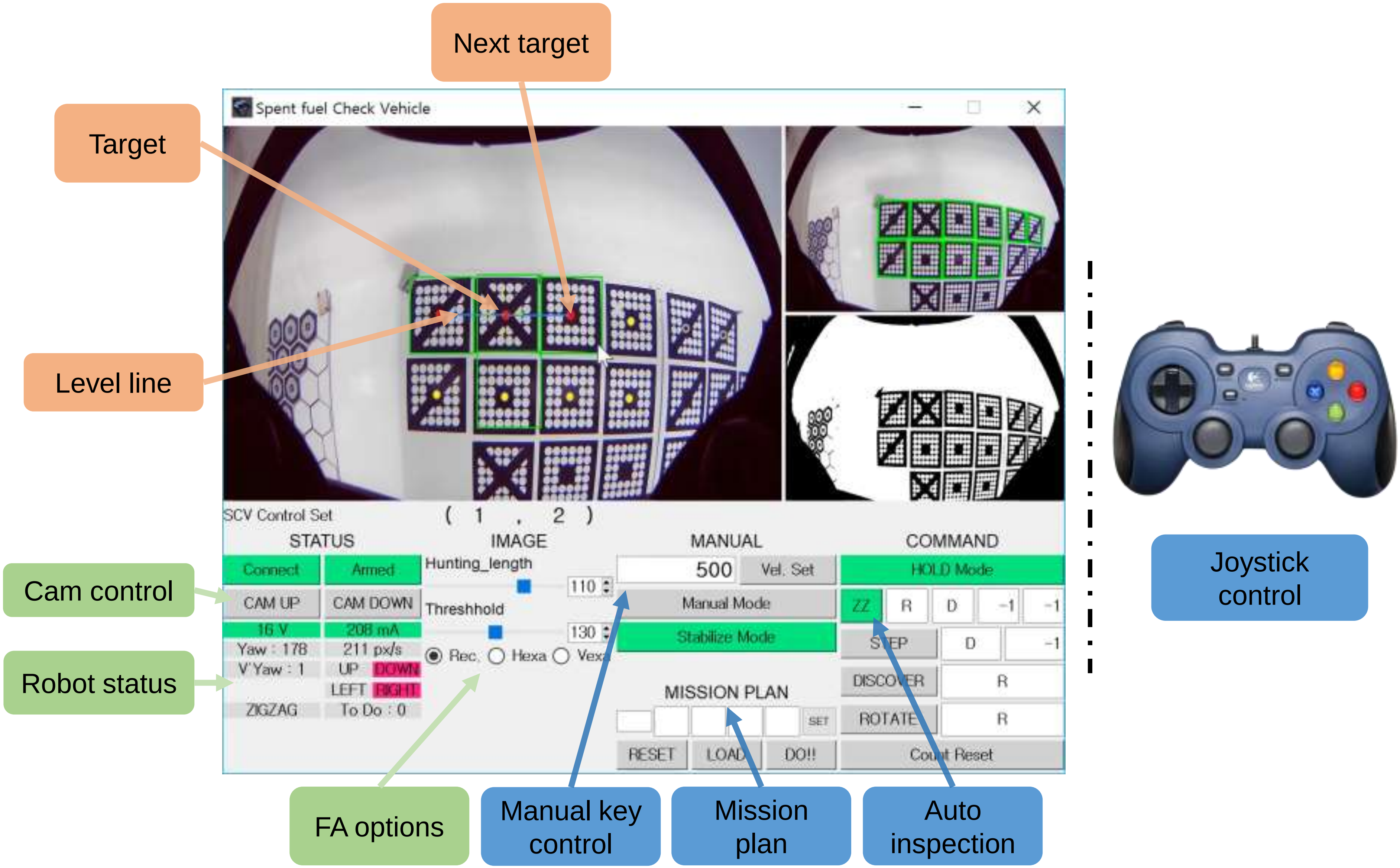
- USV can be fully controlled by a laptop computer
- The control laptop and USV are connected by wired communication through 50 meter cable
- The system does not use wireless communication or equipment, therefore it can operate stably in the spent fuel pond environment.

Control program

The main control program consists of three subprograms (image processing program, position control program and navigation/inspection program)

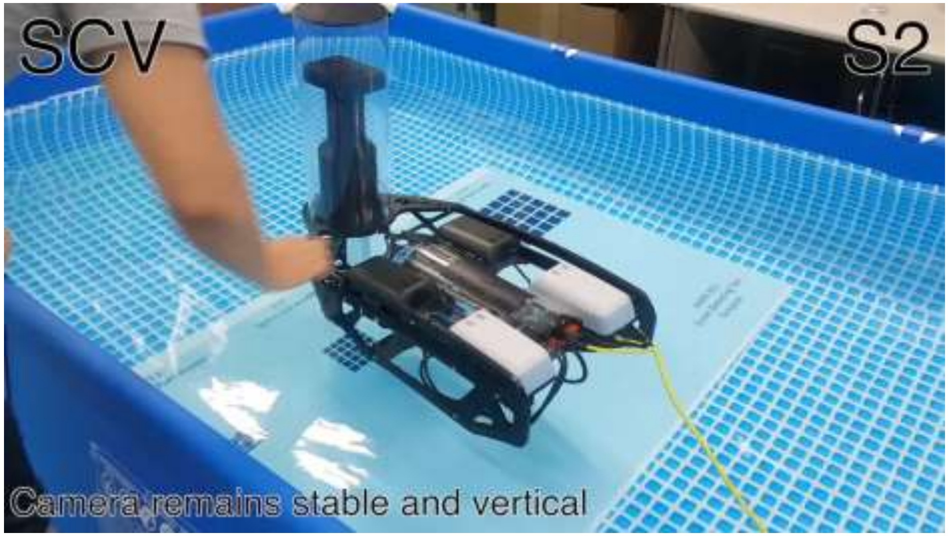
- Image processing program
- Position control program
- Navigation/inspection program

Control UI


Next target
Target
Level line
Cam control
Robot status
FA options
Manual key control
Mission plan
Auto inspection
Joystick control
Spent fuel Check Vehicle
SCV Control Set
(1 , 2)
STATUS
IMAGE
MANUAL
COMMAND
Connect
Armed
CAM UP
CAM DOWN
16 V
208 mA
Yaw : 178
211 px/s
V'Yaw : 1
UP DOWN
LEFT RIGHT
ZIGZAG
To Do : 0
Hunting_length
110
Threshhold
130
Rec.
Hexa
Vexa
500
Vel. Set
Manual Mode
Stabilize Mode
MISSION PLAN
SET
RESET
LOAD
DO!!
HOLD Mode
ZZ
R
D
-1
STEP
DISCOVER
ROTATE
Count Reset

Implementation

- ❖ S1 : always remains buoyant, no part fall and the camera remains protected from water.
- ❖ S2 : camera remains stable and vertical
  - ❖ images are sharp at 1/10s exposure taken with a 250mm lens
  - ❖ account small waves



Implementation

- S3 : carried in a plane, prepared by a single user.

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Implementation

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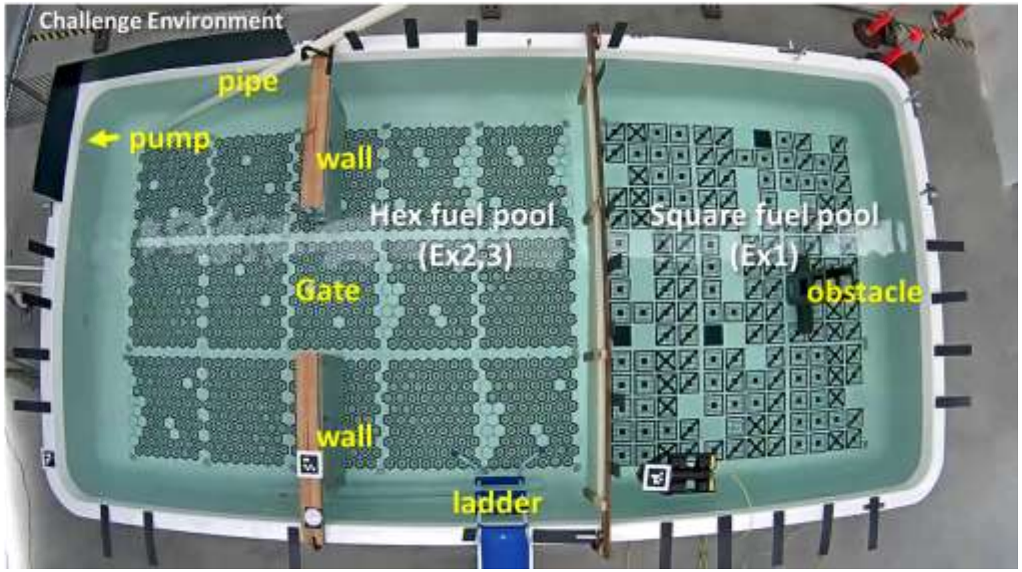
  - ❖ No external guiding infrastructure is allowed.
  - ❖ system for moderate circulation streams generated by water pumps.
  - ❖ follow straight lines, systematically scanning the fuel assemblies.

Experiment protocol

Experiment pool



- Due to safety and security concerns, all experiments take place in a safe environment without any radiation and without any risk of radioactive contamination.
- indoor swimming pool: 8.6 m x 3.8 m x 1.2 m
- Pool walls: 15-20 cm above the water level
- Fuel assembly:
    - Square: 20 cm x 20 cm
    - Hexagonal: 12 cm in diameter

FA types used in the experiments

ICVD(Improved Cerenkov Viewing Device) dummy

Experiment 1

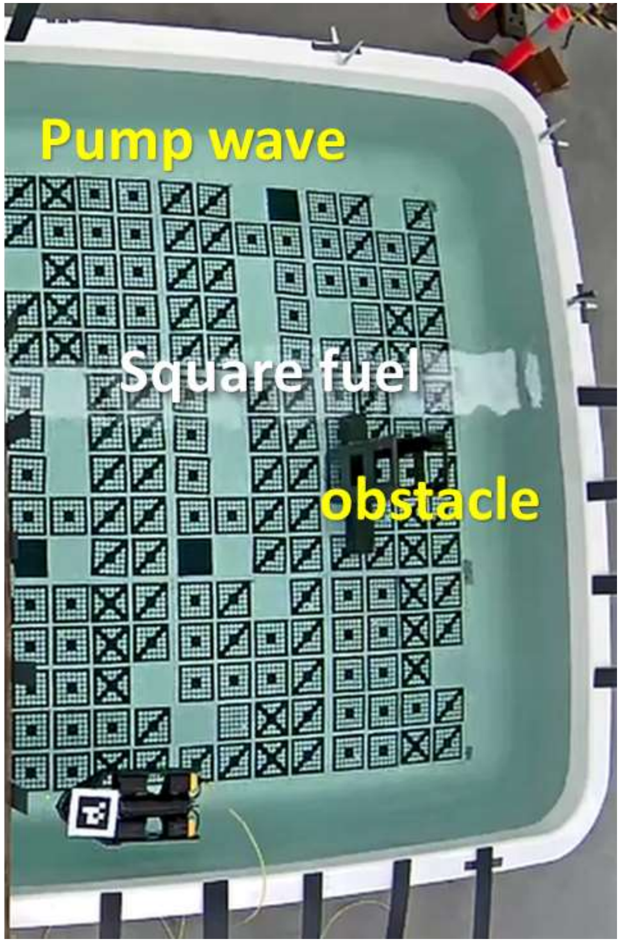
Experiment 1

Objective

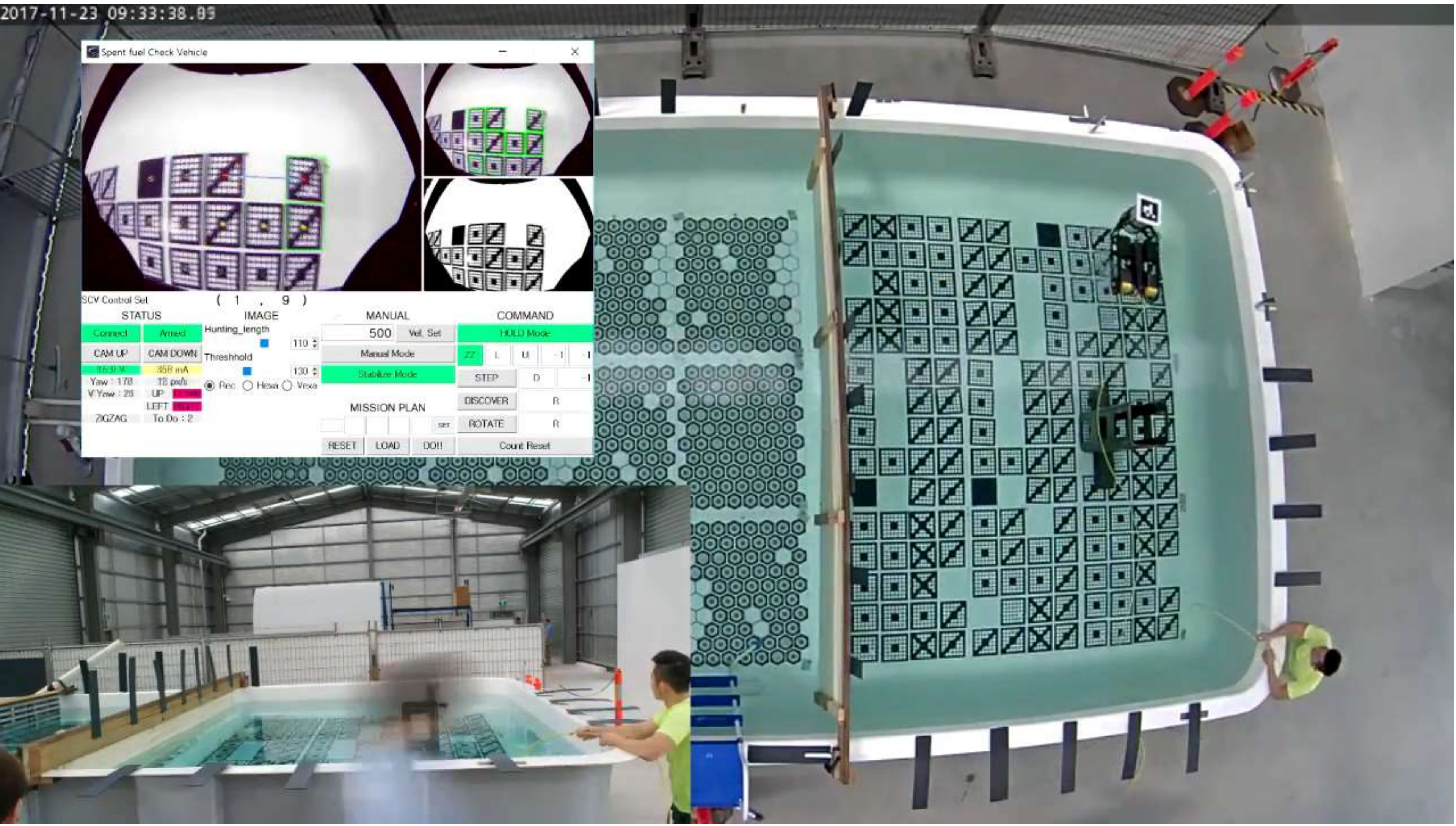
- Square fuel
- Inspect all FAs in 20 min.

The assessment criteria

- Cover all of the FAs
- Trajectory is aligned with the FA pattern
- Motion and speed remains under control
- Video: clear (stable, not blur) frames featuring all FAs



Experiment 1



Experiment 2

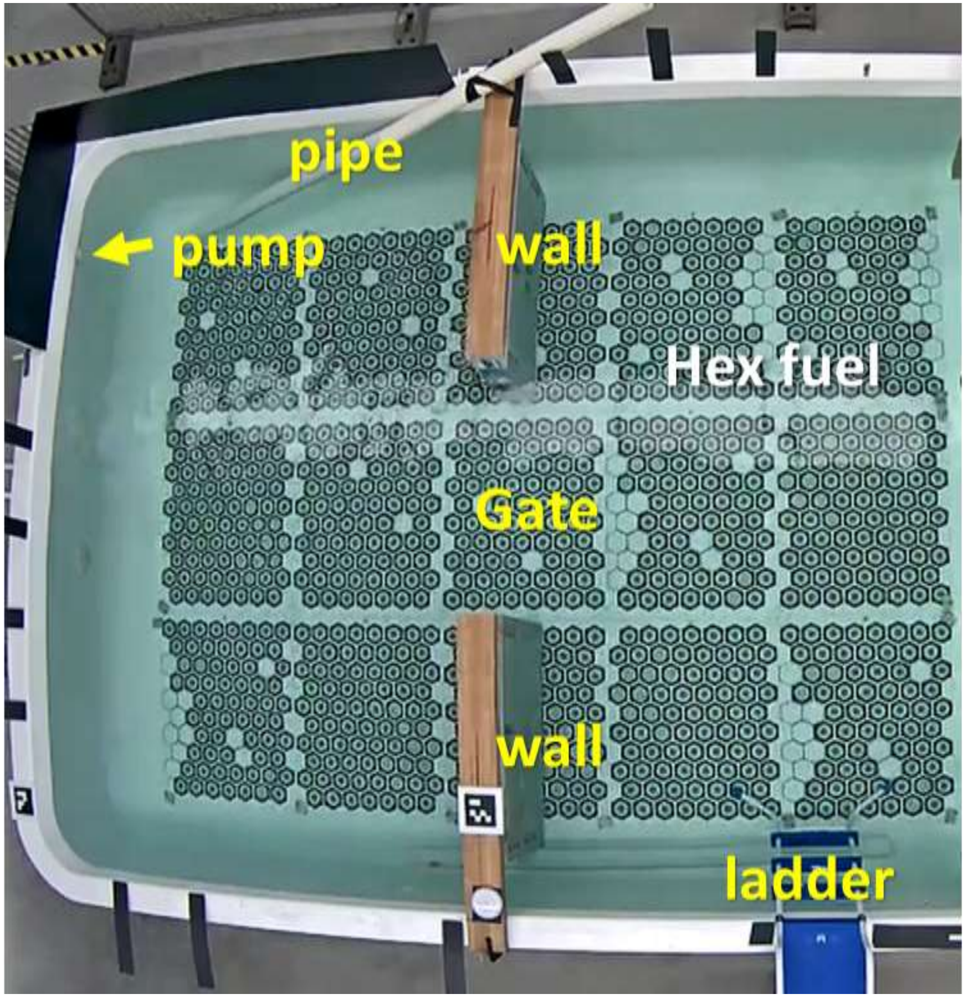
Experiment 2

Objective

- Hex fuel
- Inspect all FAs in 20 min.

The assessment criteria

- Cover all of the FAs
- Trajectory is aligned with the FA pattern
- Motion and speed remains under control
- Video: clear (stable, not blur) frames featuring all FAs



Experiment 2

Experiment 3

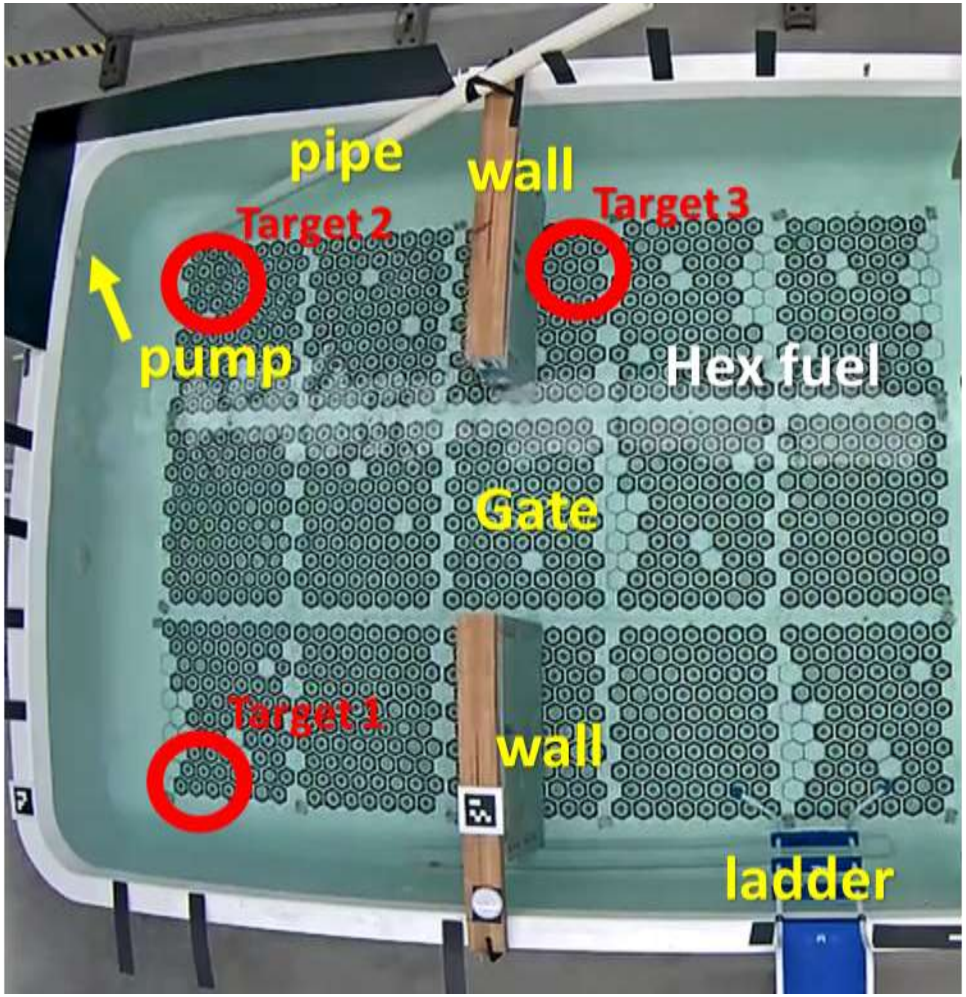
Experiment 3

Objective

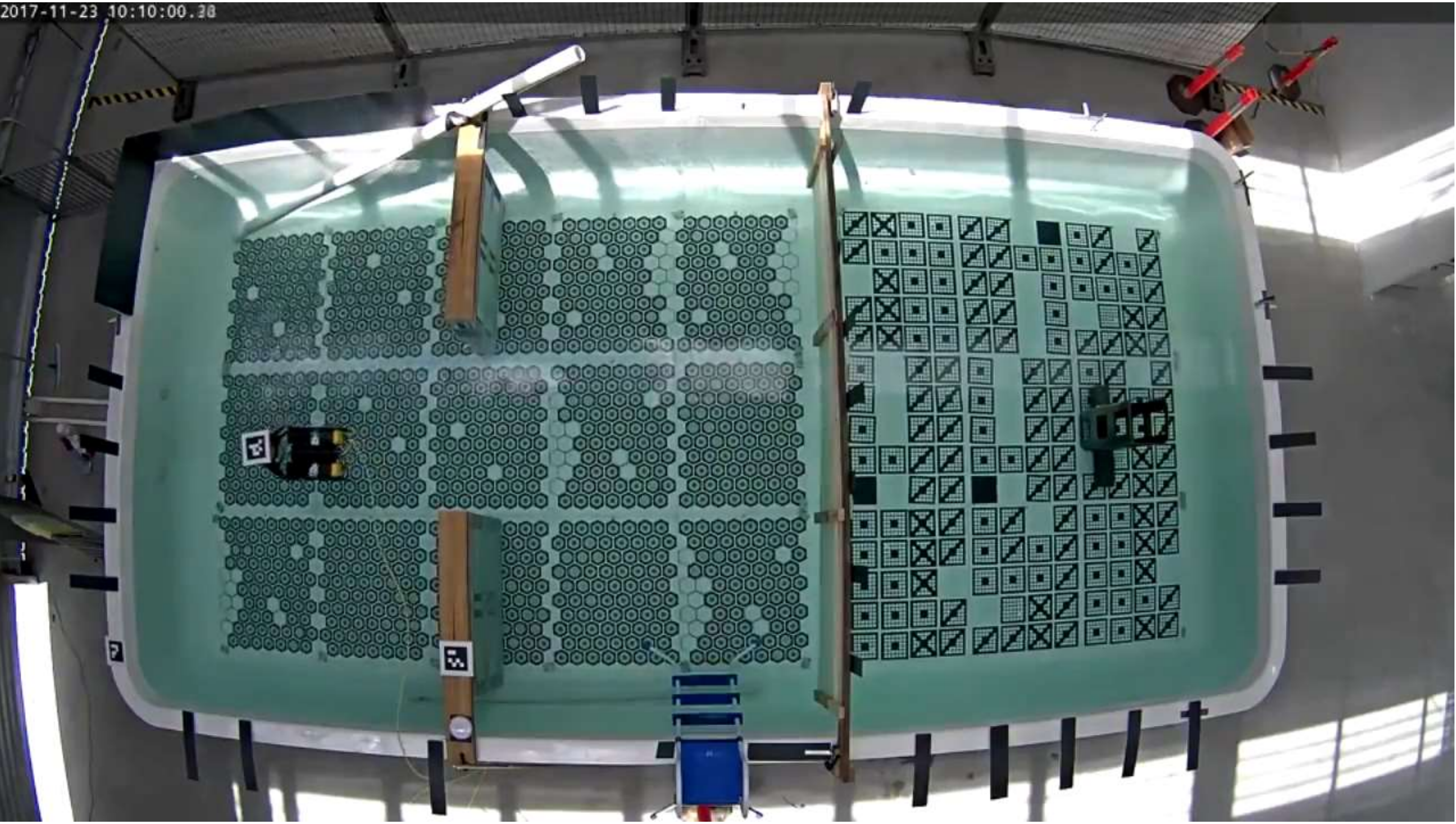
- Hex fuel
- Inspect random selection of 3 FAs in 10 min.
- Hovering over each FA for 1 min.
- Target FAs are located in difficult to access parts of the pond

The assessment criteria

- Optimal trajectory and speed of the USV
- 1 minute-long stable videos featuring specified FA

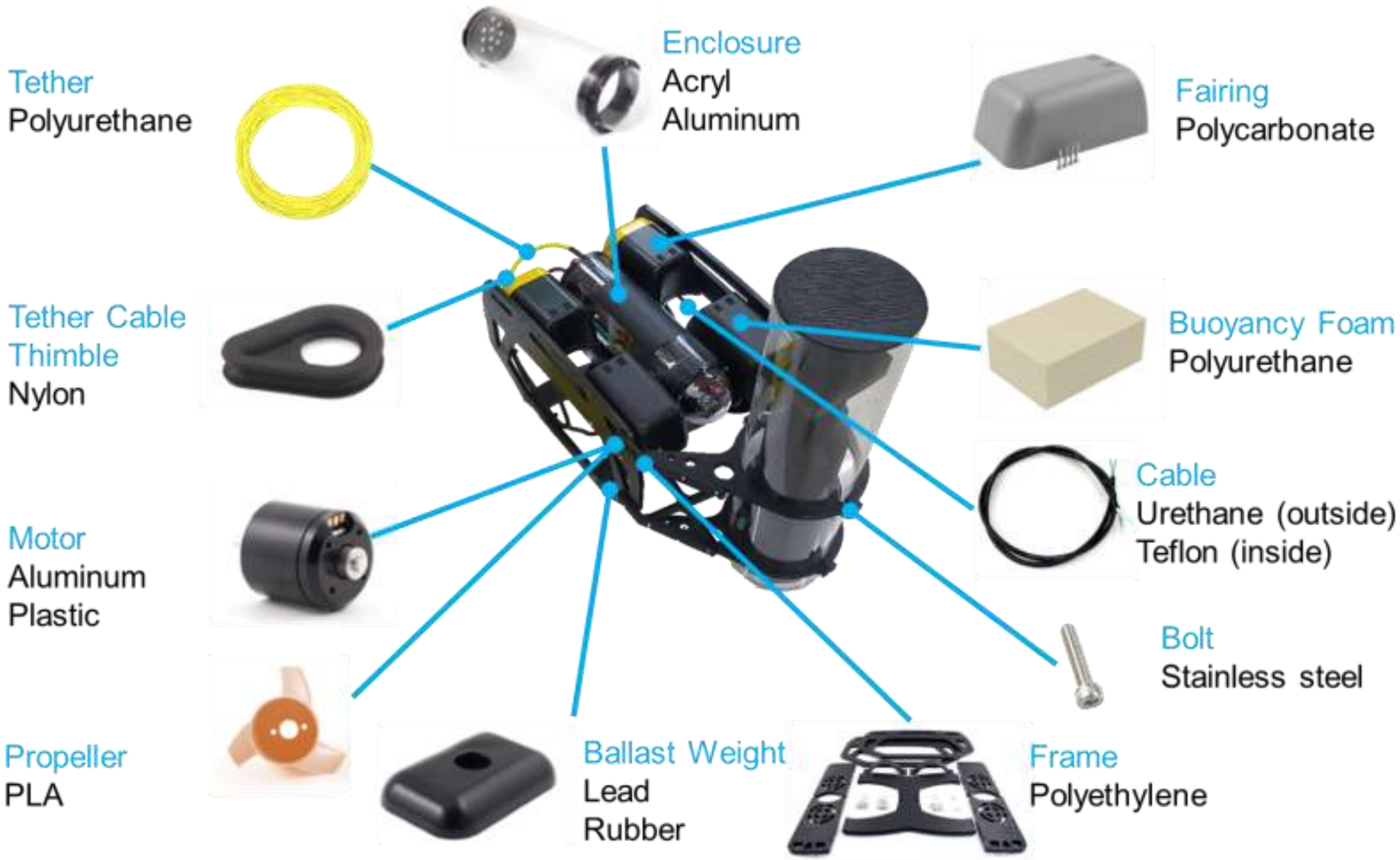


Experiment 3

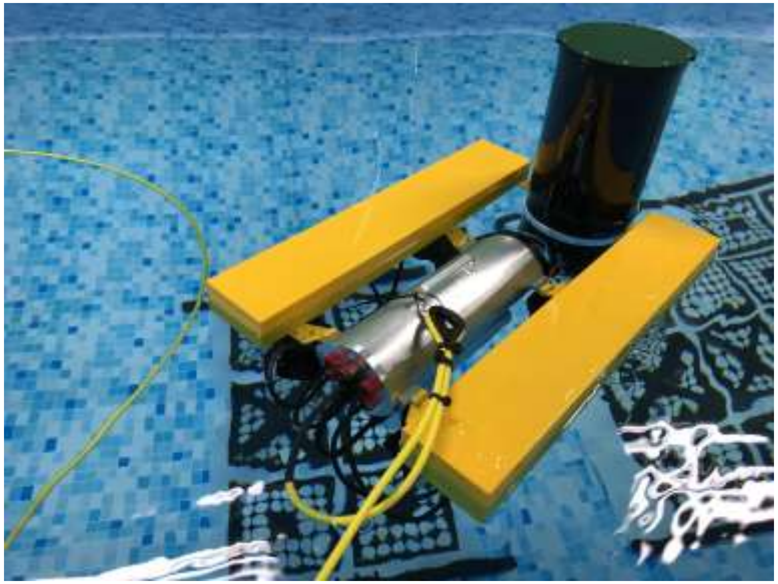


Contamination clean-up

Material safety



Robot redesign



- Frame: stronger, simpler
- Aluminum, stainless steel material
- Smaller, lighter
- Less bots, parts
- Hooks for load/unload
- Easy decontamination

Training (11/13)

- General understating of the robot
- SCV robot assemble training
- Control software training

Training @ IAEA

Training @ Vienna Model Basin Ltd

Training (11/13)

- Robot deploy training

Datastart, Hungary



Univ. of Manchester, UK


SCV, KAERI



Proof-of-concept in Finland

- Loviisa Nuclear power plant
- 18.11.19~30 (2 weeks)
- IAEA inspectors:
  - Dimitri Finker
  - Andrey Sokolov
- Test robots
  - Datastart, Hungary
  - Univ. of Manchester, UK
  - SCV, KAERI
- Test Schedule
  - 11.19~23: KAERI, Hungary
  - 11.26~30: KAERI, Hungary, Univ. of Manchester