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NASA Johnson Space Center
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Spaceflight Systems Division

The Evolution of On-Board Emergency Training for the International Space Station Crew

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Improving Space Operations Workshop

Brief Introduction

- The crew of the International Space Station (ISS) receives extensive ground-training in order to safely and effectively respond to any potential emergency event while on-orbit, but few people realize that their training is not concluded when they launch into space
- The evolution of the emergency On-Board Training events (OBTs) has recently moved from paper “scripts” to an intranet-based software simulation that allows for the crew, as well as the flight control teams in Mission Control Centers across the world, to share in an improved and more realistic training event
- This emergency OBT simulator ensures that the participants experience the training event as it unfolds, completely unaware of the type, location, or severity of the simulated emergency until the scenario begins

Overview

- General background information
  - Potential Emergencies Onboard ISS
  - Emergency Training Flow Scope
  - Purpose of Emergency On-Board Training (OBT)
- How we started – Paper “Scripts”
- How We Improved Training Quality
- Emergency OBT Simulator
  - Crew, Instructor, and Flight Controller Interfaces
- Synergy and Leveraged Codebase
  - CSA-CP Emulator
- Risk Reduction Conclusions

Potential Emergencies Onboard ISS

- Fire
  - Burning odor, smoke, flames
  - Could be located behind or inside of a rack
- Rapid Depressurization
  - MMOD strike
  - Visiting Vehicle docking/berthing malfunction
- Toxic Atmosphere
  - Hazardous substance spill
  - Ammonia breach from external cooling system into US Segment internal cooling system and cabin atmosphere via Interface Heat Exchanger

Emergency Training Flow Scope

- Entire crew training template is ~2.5 years once assigned to a specific Increment crew
  - Emergency Training is spaced out over the final 18 months on the ground
    - Classroom lessons
    - Mockup-based lessons
    - Emergency Generic Scenarios
    - Emergency Mastery evaluations
    - Assigned-Crew Emergency Scenarios
      - Three executions of a full 3-member Increment crew
      - Two executions as a 6-member ISS crew

Purpose of Emergency On-Board Training (OBT)

- Provide proficiency drills for responding to an emergency onboard ISS
  - Keeps memorized response actions and learned-skills fresh
  - Increases crew preparedness and reduces risk
- Each 3-member Increment crew executes two emergency scenario OBT drills during their six-month Expedition
  - First is ~2 weeks after their arrival
  - Second is ~2 weeks after next Soyuz arrives (around halfway through their Expedition)
- Debrief after each event to share lessons learned
  - Inputs often enlighten response strategy and can help identify areas that could be improved

How we started – Paper “Scripts”

- Separate but synchronized information was provided to the crew and the ground
- Allowed coordination between multiple control centers around the world
- Many limitations and training quality was minimal
  - Not optimal since everyone could read ahead to see how the case would unfold
  - Too much focus was devoted to “staying on script” rather than engaging in real-time decision making
  - Some crews reported that they could passively read from a script and not really get the value from engaging in a surprise set of conditions
  - It was also challenging for the crew and ground to stay on the correct page of the script and the correct page/step of the Emergency response procedures

Examples of Paper Scripts - Fire

MCC-H, MCC-M, COL-CC and SSIPC COPY ONLY

MCC-H, MCC-M, COL-CC, and SSIPC Greenboards	Crew Greenboards
Step 1.1: (Crew or ground simulate this step): There are no Columbus equipment failures or EPS Hardware Trip Cautions indicated on Caution and Warning Summary. **If VTC is still powered, the following greenboards are still present:** • COL-DMS: VTC1_Nom_Temp_MVD = 37C VTC1_Redun_Temp_MVD = 37C • COL-SYS: VTC current supports rise in VTC1 temps. **Step 1.2:** (Crew or ground simulate this step): After commanding Off Cabin Fan Assembly PDU1(2) 120V outlets (Num 23): • Cabin Fan Assembly 1, Cabin Fan Assembly 2 On-Off Status = Off **Step 1.3:** Rack smoke detectors did not annunciate. **Step 2.3:** • Fire location is not known from ISPR rack smoke detector. • A PDU Outlet Trip Caution did not annunciate. • Fire location is not known. **Step 3:** (Crew or ground simulate this step). Multiple Caution and Warning alarms/messages appear after turning off EPS Hardware for affected Fire Port(s). • For simulation purposes and situational awareness, COL-CC will power OFF half of Columbus lights: {2.110 PDU1 120V OUTLET SWITCHING GENERIC}, step 4 (ESA SODF: EPDS: NOMINAL) for PDU1 Outlet 21.	<Seen only on Crew copy of this message>
Step 6: (Crew or ground simulate this step). After simulating Columbus powerdown: • For simulation purposes and situational awareness, COL-CC will power OFF remaining Columbus lights: {2.210 PDU2 120V OUTLET SWITCHING GENERIC}, step 4 (ESA SODF: EPDS: NOMINAL) for PDU2 Outlet 21.	<Seen only on Crew copy of this message>
Step 8: All equipment stowage in Columbus is per the current onboard stowage configuration. All Columbus IMV valves are in the expected positions as called out by the procedure.	<Seen only on Crew copy of this message>

CREW COPY ONLY

MCC-H, MCC-M, COL-CC, and SSIPC Greencards	Crew Greencards
	COL1D2_S2 — 254 — COL1D5-1 — 2 COL1FD2-1 — 2 — COL1D5-2 — 2 COL1SF3-1 (OVHD FWD Standoff) — 3 — COL1A5-1 — 3 COL1A2_E1 (Slclab) — 4 — COL1A5-2 — 3 COL1A2_I1 (Slclab) — 4 — Air Quality Monitor — 4 COL1A2S-1 (APT Deck Standoff) — 4 Step 3: (Crew or ground simulate this step). Multiple Caution and Warning alarms/messages appear after turning off EPS Hardware for affected Fire Port. • For simulation purposes and situational awareness, COL-CC will power OFF half of Columbus lights. NOTE- Columbus lights can only be powered back ON by COL-CC or PCS commands (see item #2 in NOTE box above).
Seen only on control center copies of this message	Step 4: Do not perform actual sampling. 5-minute fire port resample indicates CO levels are rising at 5 ppm per minute. Make recommendation to ground based on results of sampling. NOTE: Columbus cabin background levels: CO = 177ppm, HCl = 6.2ppm, HCN = 4.8ppm Step 5: (Crew or ground simulate this step). After simulating Columbus powerdown: • For simulation purposes and situational awareness, COL-CC will power OFF remaining Columbus lights. NOTE- Columbus lights can only be powered back ON by COL-CC or PCS commands (see item #2 in NOTE box above).
Seen only on control center copies of this message	Step 6.1: Do not perform actual sampling. 5-minute fire port resample indicates CO levels are rising at 5 ppm per minute. NOTE: Columbus cabin background levels: CO = 184ppm, HCl = 6.5ppm, HCN = 4.8ppm Step 6.2: Remove PFE from locker, attach rack nozzle, and simulate discharging PFE into fireport.
Seen only on control center copies of this message	Step 8: Review (4.1 EQUIPMENT RETRIEVAL). Estimate time needed to perform these actions for Columbus. All Columbus IMV valves and the hatch MPEV are in the expected positions as called out by the procedure. Simulate closing Columbus hatch per decal. DO NOT actually

Examples of Paper Scripts - Rapid Depress

GROUND COPY ONLY

Crew Action Checkpoints per Crew Procedures	Time since Alarm (estimated)	Data for the Control Centers
		~1.1 mm Hg/min
ММИ2-СУ (SM) hatch closed	00:47:00	For simulation purposes the crew will call down hatch status. Proceed to the next action only after crew calldown.
ПхО-СУ (DC) hatch closed	00:49:00	For simulation purposes the crew will call down hatch status. Proceed to the next action only after crew calldown.
Check $P_{[ИЗ]}$	00:51:00	• FGB ПГО pressure is 696 mm Hg and dropping at ~1.1 mm Hg/min • SM [PO] pressure is 696 mm Hg and dropping at ~1.1 mm Hg/min • DC-1 pressure is 695 mm Hg and NOT dropping • USOS pressures are ~696 mm Hg and dropping at ~1.1 mm Hg/min
[СО-СУ] (SM) hatch closed	00:52:00	For simulation purposes the crew will call down hatch status. Proceed to the next action only after crew calldown.
Check $P_{[ИЗ]}$	00:54:00	• FGB ПГО pressure is 693 mm Hg and dropping at ~1.2 mm Hg/min • SM [PO] pressure is 693 mm Hg and dropping at ~1.2 mm Hg/min • USOS pressures are ~693 mm Hg and dropping at ~1.2 mm Hg/min
ПГО-СУ (SM) hatch closed	00:56:00	For simulation purposes the crew will call down hatch status. Proceed to the next action only after crew calldown.
Check $P_{[ИЗ]}$	00:58:00	• FGB ПГО pressure is 689 mm Hg and dropping at ~1.2 mm Hg/min • SM [PO] pressure is 691 mm Hg and NOT dropping • USOS pressures are ~689 mm Hg and dropping at a rate of ~1.2 mm Hg/min
ПхО-СУ (FGB) hatch closed	00:59:00	For simulation purposes the crew will call down hatch status. Proceed to the next action only after crew calldown.
Check $P_{[ИЗ]}$	01:01:00	• FGB ПГО pressure is 686 mm Hg and dropping at ~1.2 mm Hg/min • SM [PO] pressure is 686 mm Hg and NOT dropping • USOS pressures are ~686 mm Hg and dropping at a rate of ~1.2 mm Hg/min
ПГО-ГА hatch closed	01:03:00	For simulation purposes the crew will call down hatch status. Proceed to the next action only after crew calldown.
		• USOS pressures are ~700 mm Hg and dropping at
		calldown.

Checkpoints for Crew Actions per EMER-1 Procedure	Time Elapsed since Alarm (estimated)	Data for the Crew
Verify $T_{тах}$ > 00:10:00		($T_{тах}$ = 225 min)
ПГО-СУ (SM) hatch closed	00:56:00	$P_{[ИЗ]}$ = 691 mm Hg
Check $P_{[ИЗ]}$	00:58:00	$P_{[ИЗ]}$ = 689 mm Hg ($t_{тах}$ ~ 50 seconds)
ПхО-СУ (FGB) hatch closed	00:59:00	$P_{[ИЗ]}$ = 688 mm Hg
Check $P_{[ИЗ]}$	01:01:00	$P_{[ИЗ]}$ = 686 mm Hg
Verify $T_{тах}$ > 00:10:00		($T_{тах}$ = 220 min)
ПГО-ГА hatch closed	01:03:00	$P_{[ИЗ]}$ = 684 mm Hg
Check $P_{[ИЗ]}$	01:05:00	$P_{[ИЗ]}$ = 684 mm Hg
ММИ1-СУ (FGB) hatch closed	01:06:00	$P_{[ИЗ]}$ = 684 mm Hg
Check $P_{[ИЗ]}$	01:07:00	$P_{[ИЗ]}$ = 684 mm Hg
ММИ1-СУ hatch closed		
БО-СУ hatch closed		Report to MCC
DEPRESS DRILL COMPLETE		

Do not restore ISS communication systems to the nominal configurations.
Restore Soyuz communication systems to the nominal configurations.

The crews will return Soyuz vehicles to the original configuration according to crew procedure "SOYUZ ASCENT/DESCENT" (Section 1.4.2, step 3, p. 27 "TURNING OFF COMMUNICATION S").

ММИ2-СУ (SM) hatch closed	00:47:00	
Verify $T_{тах}$ > 00:10:00		($T_{тах}$ = 240 min)
ПхО-СУ (DC) hatch closed	00:49:00	$P_{[ИЗ]}$ = 698 mm Hg
Check $P_{[ИЗ]}$	00:51:00	$P_{[ИЗ]}$ = 696 mm Hg ($t_{тах}$ ~ 57 seconds)
[СО-СУ] (SM) hatch closed	00:52:00	$P_{[ИЗ]}$ = 695 mm Hg
Check $P_{[ИЗ]}$	00:54:00	$P_{[ИЗ]}$ = 693 mm Hg

Examples of Paper Scripts - Ammonia Leak

MCC-H, MCC-M, COL-CC, and SSIPC COPY ONLY

When ready, crew informs MCC-H and MCC-M, "Starting the Increment 28 Ammonia Leak OBT Exercise."

Crew's memorized initial response:

- Simulate donning gas masks, pushing ATM button, and closing Node 1 Aft Hatch to isolate the USOS.

2.3S8 IFHX NHS LEAK DETECTED - WARN (SODF: WARN: 2.S TCG)

MCC-H, MCC-M, COL-CC, and SSIPC Greenboards	Crew Greenboards
COL ITCS Data: • WPA1_ACCUM_ABS_PRESS1_VTC: 255 kPa • WPA1_ACCUM_ABS_PRESS2_VTC: 255 kPa • WPA2_ACCUM_ABS_PRESS1_VTC: 255 kPa • WPA2_ACCUM_ABS_PRESS2_VTC: 255 kPa S.25S COL IFHX NHS LEAK DETECTED: • This procedure is completed successfully after Ground simulates the applicable steps. Ground teams discuss forward plan, as time permits.	<Seen only on Crew copy of this message>

Crew and MCC discuss forward plan, as time permits.

AMMONIA LEAK DRILL RESPONSE ACTIONS COMPLETE

Crew will return all equipment and systems to their nominal locations and conditions prior to establishing their initial locations for the next EMER OBT drill.

END INCREMENT 28 AMMONIA LEAK OBT EXERCISE.

Many Caution events listed.

CREW COPY ONLY

AMMONIA DETECTION KIT CUE CARD #2 (located in the Ammonia Detection Kit)

MCC-H, MCC-M, COL-CC, and SSIPC Greenboards	Crew Greenboards
<Seen only on control center copies of this message>	Step 4: Simulate compressing the pump for ten (10) strokes. Step 5: No blue reaction on HI tubes after 10 strokes (both samples). Step 8: Simulate compressing the pump for ten (10) strokes. Step 9: Blue reaction to the 60ppm mark of MED tubes after 10 strokes (both samples)

AMMONIA RESPIRATOR KITS

- Review the contents of the ammonia respirator kits and their instructions.
- Estimate the length of time needed to deploy the Ammonia Respirator Kits from the FGB stowage locations, and provide this information in the debrief.

DONNING OF AMMONIA RESPIRATOR & CARTRIDGE CHANGEOUT (located in the Ammonia Respirator Kits)

MCC-H, MCC-M, COL-CC, and SSIPC Greenboards	Crew Greenboards
<Seen only on control center copies of this message>	Simulate all steps. Step 2.11: Negative and positive pressure checks are completed Satisfactorily.

Crew and MCC discuss forward plan, as time permits.

AMMONIA LEAK DRILL RESPONSE ACTIONS COMPLETE

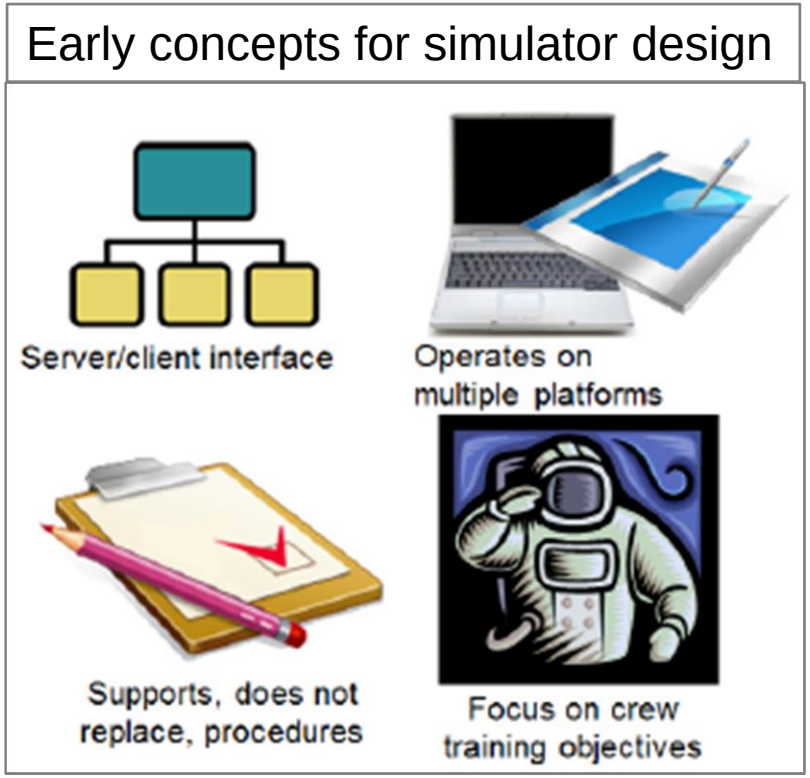
Return all equipment and systems to their original location/configuration prior to establishing initial locations for the next EMER OBT drill.

END INCREMENT 28 AMMONIA LEAK OBT EXERCISE.

END OF OCA MESSAGE.

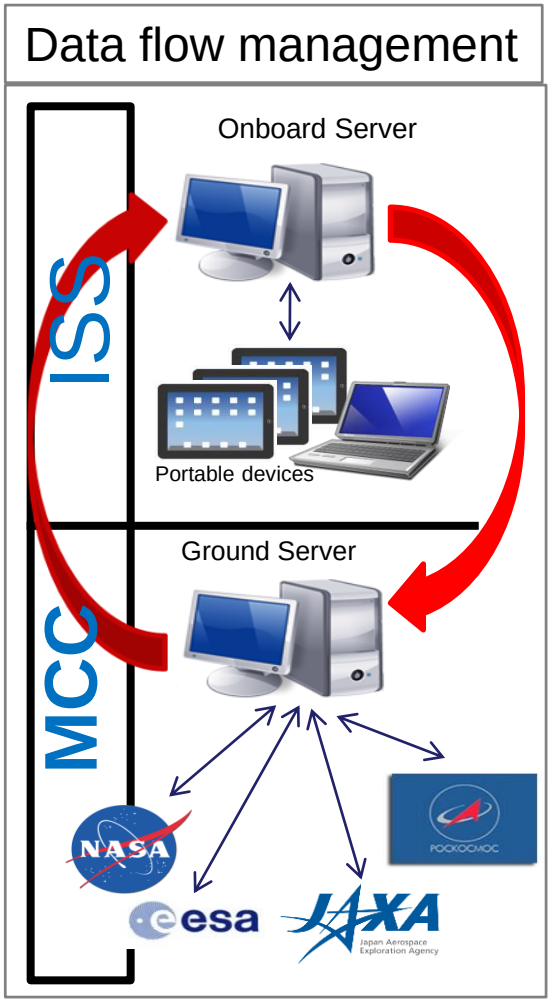
How We Improved Training Quality

- Significant challenge to come to an agreement between all International Partners on scope and a common approach for novel Emergency OBT simulator
  - Representatives from US, Russia, Europe, and Japan
  - All crewmembers, regardless of affiliation, participate in the same training events together, so the only solution is a single simulator



How We Improved Training Quality

- Simulator Requirements
  - Create a dynamic simulation that gives real-time data feedback
  - Maintain real-time interface between Mission Control Centers and crew during OBTs
  - Provide flexibility for decision making during drill execution
  - Materially reduce instructor and flight control team man-hour costs involved with developing, updating, and maintaining emergency OBT cases/scenarios
  - Introduce an element of surprise to emergency scenarios so the team can't tell the outcome of the case by reading ahead in a paper script

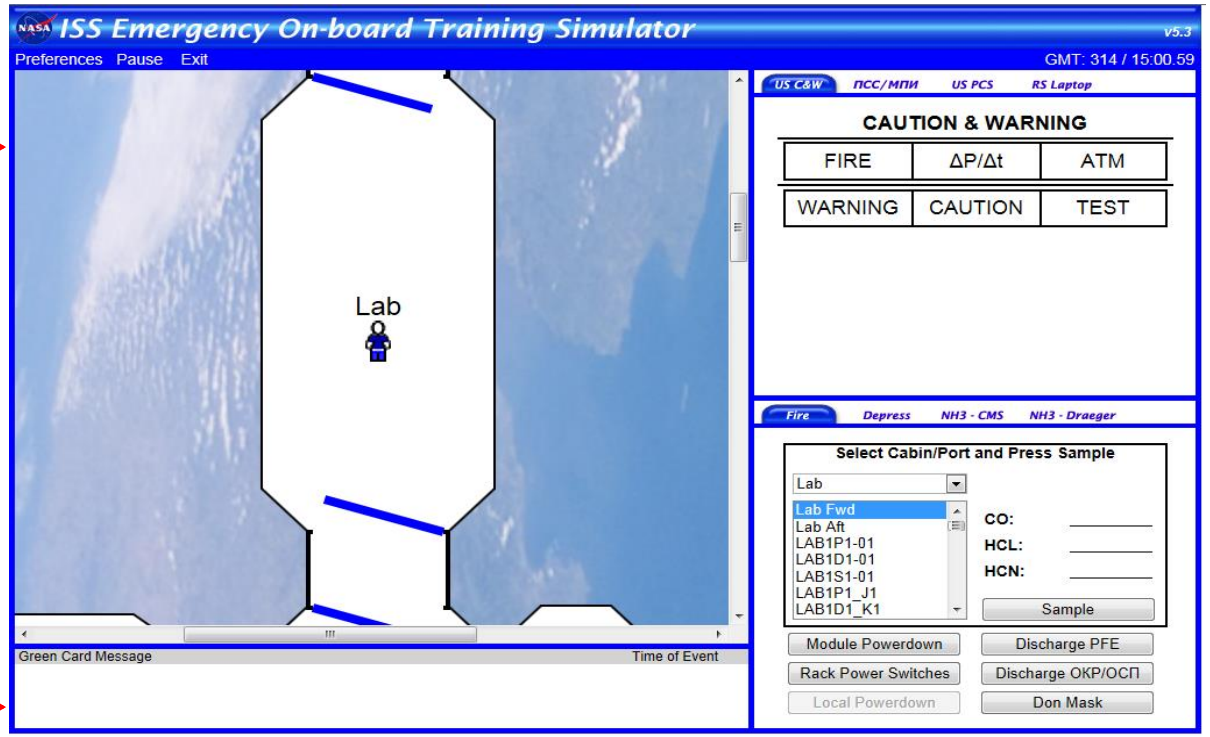


Emergency OBT Simulator

- Enables crewmembers to move around the ISS receiving dynamic emergency signatures and new information at the correct pace for a simulated emergency
  - Runs on crew iPads as well as Station Support Laptops
- Crews can make decisions, make errors, and learn or adjust responses based on results and feedback
- Ground teams see the results of crew actions in their downlinked data, have additional insight into simulated vehicle data signatures that they can provide to the crew
  - Crew/ground interaction overall is much more realistic

Emergency OBT Simulator Implementation

Crew Interface - Display Layout



Graphical view of ISS

C&W Panels/Laptops

Virtual H/W

Greencard messages

Crew Interface – Fire Scenario

Preferences
(turn hatch boxes on/off, add hatch names, change language)

Smoke/Fire Icon – will disappear when fire is EXTINGUISHED

GMT Clock: (Red or Yellow highlights indicate loss of comm with the server)

Mobile avatar represents crewmember's location

Hatch boxes OFF: (Clicking on hatch will open/close hatch)

US PCS (also available: ПСС/МПИ, US C&W panel, and RS Laptop - C&W)

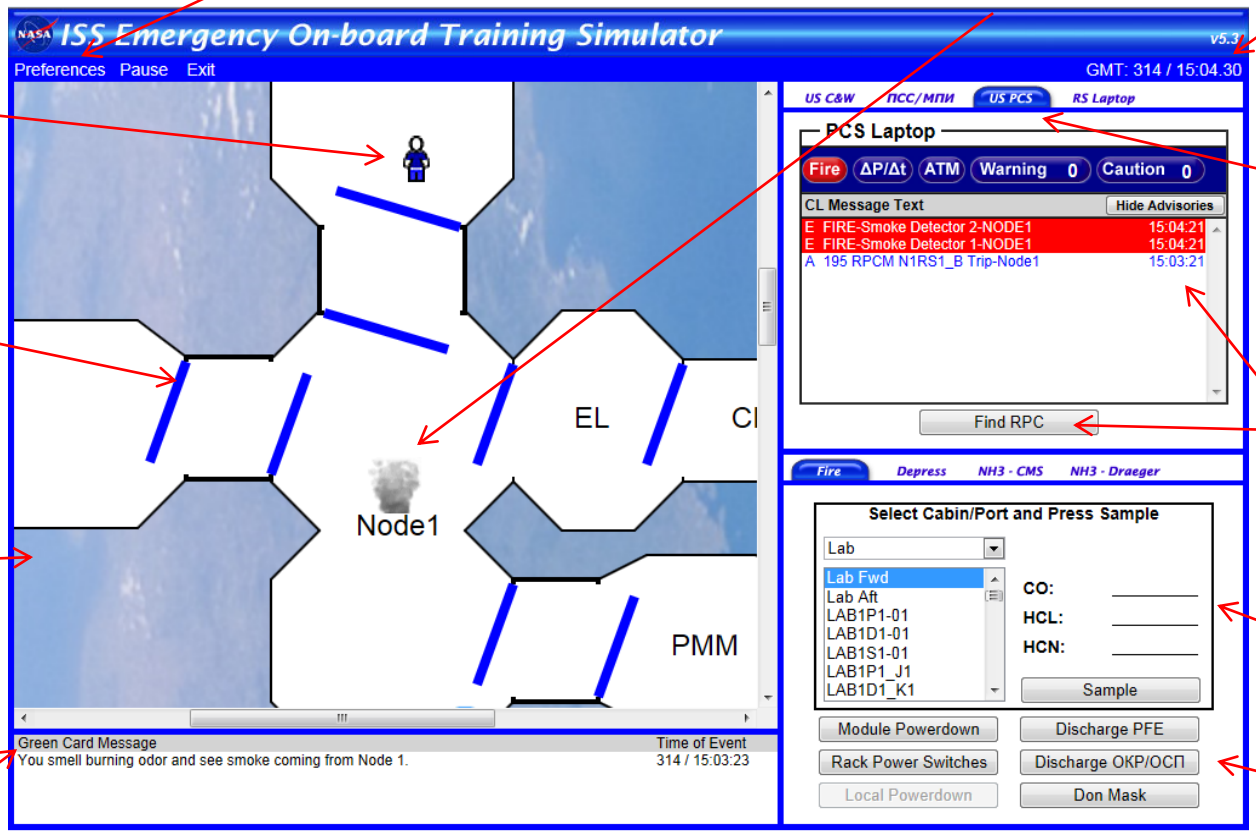
US PCS C&W Summary – provides access to Advisories and 'Find RPC' button

Can **resize** ISS via 2-finger pinch/scroll on iPAD only

CSA-CP samples (choose location then tap Sample)

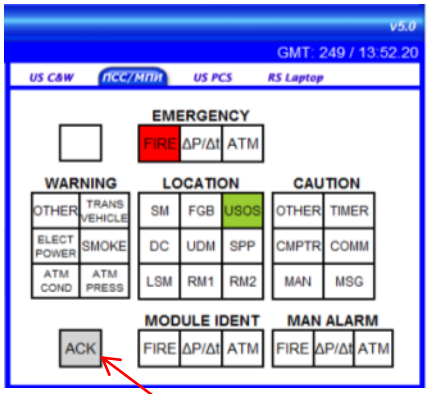
Real-time greencards

Virtual H/W

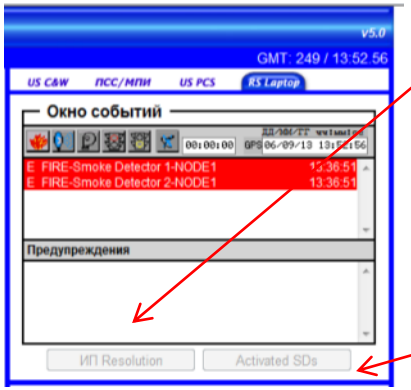


Crew Interface – C&W Panel/Laptop Capability

•Provides ability to annunciate and silence C&W tones

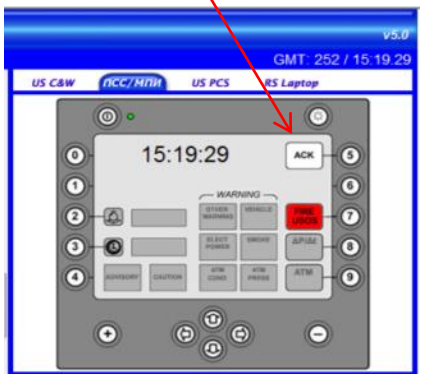


•Provides ability to annunciate and silence C&W tones

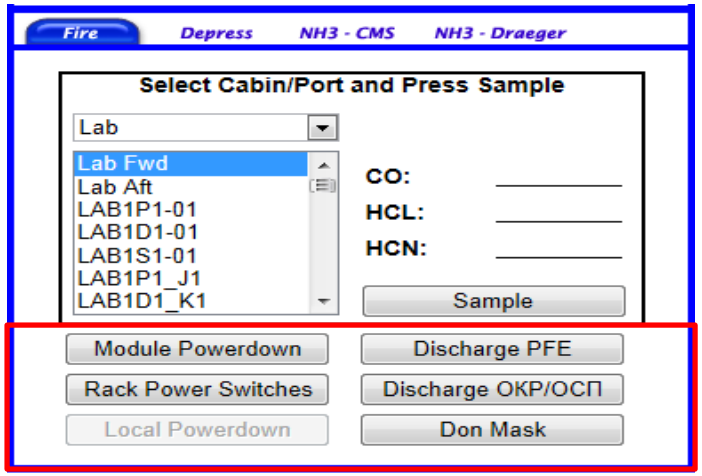


•Provides C&W messages and ИП resolution information

•Provides RS smoke detector annunciation details



Crew Interface – Virtual Hardware Capability



Module Powerdown

- Will bring up a separate window allowing user to powerdown each individual power feed detailed in the module powerdown sections of the EMER book

Rack Power Switches

- Provides insight into power status of each rack
- Provides user the ability to switch a rack power switch OFF

Local Powerdown

- Provides user the ability to complete powerdowns behind specific fireports
- Must select fireport prior to clicking this button

Discharge PFE; Discharge OKP/OCП

- Provides user the ability to discharge an extinguisher
- Must select location or fireport prior to clicking this button

Don Mask

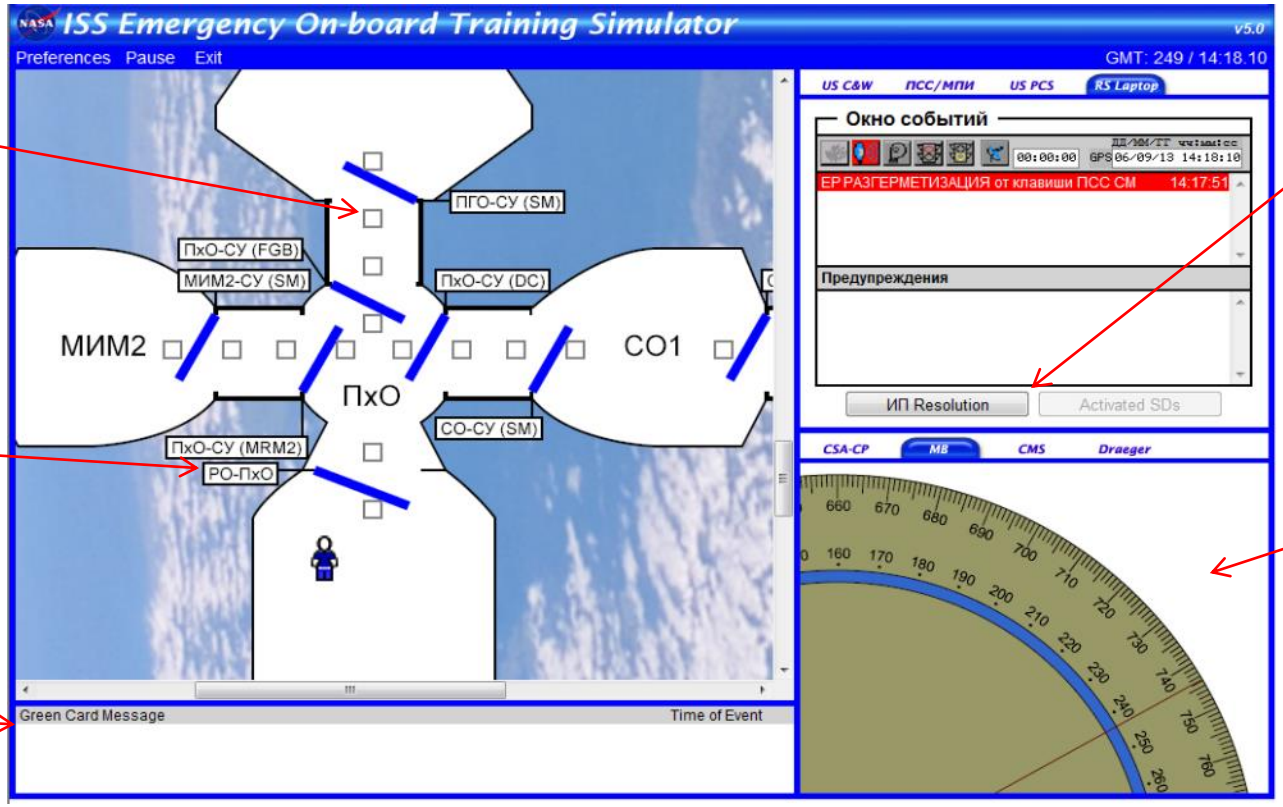
- Provides ability to don PBA, Respirator, or ИПК
- Icons will appear next to avatar showing which mask is donned
- Masks have time limits coded; Will receive pop-up message when mask is exhausted
- If PBA is donned, bottle pressure gauge is displayed, showing remaining oxygen

Crew Interface – Rapid Depress Scenario

Hatch boxes ON: (clicking a hatch box will move the avatar to that side of the hatch and close the hatch)

Hatch names ON

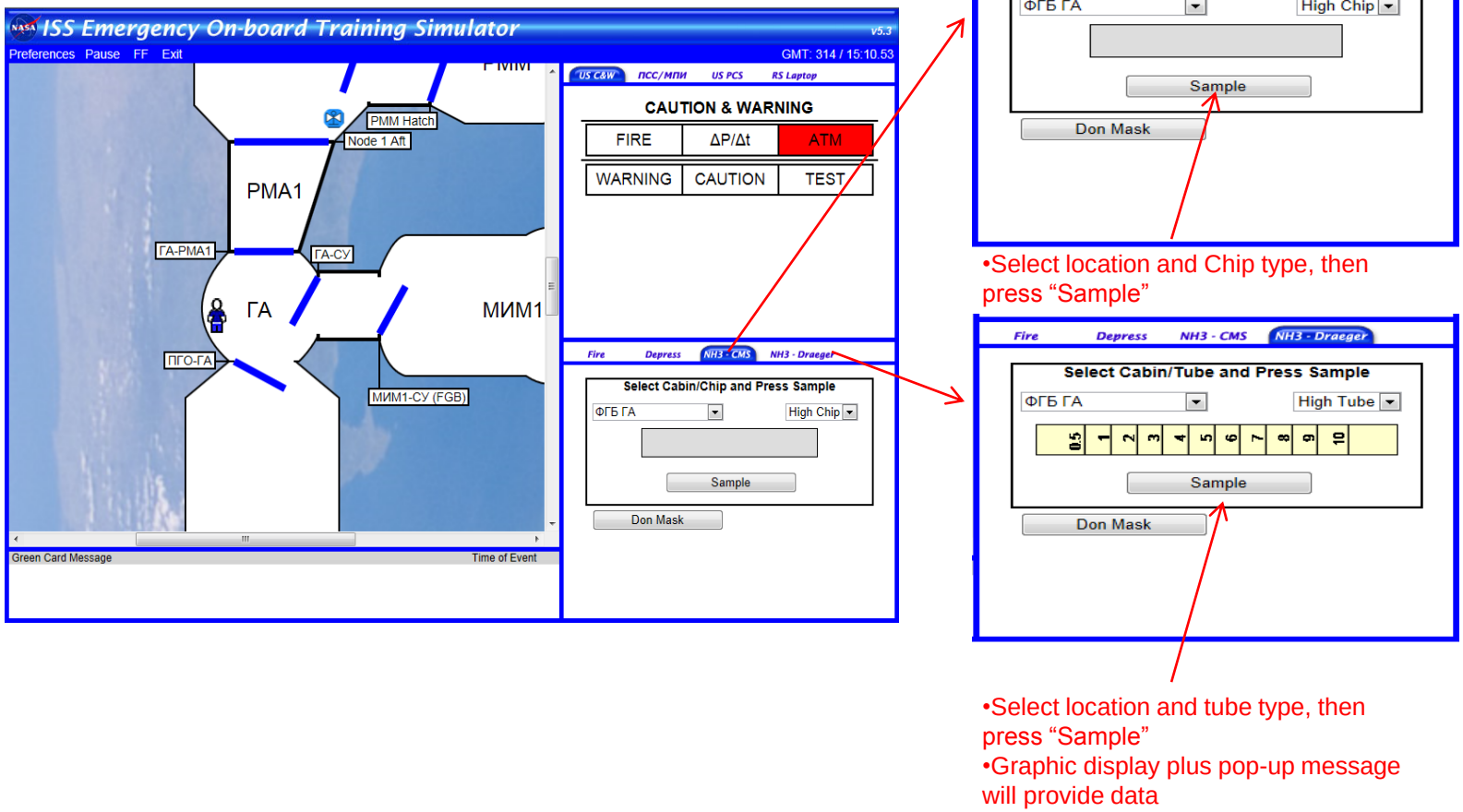
Real-time greencards



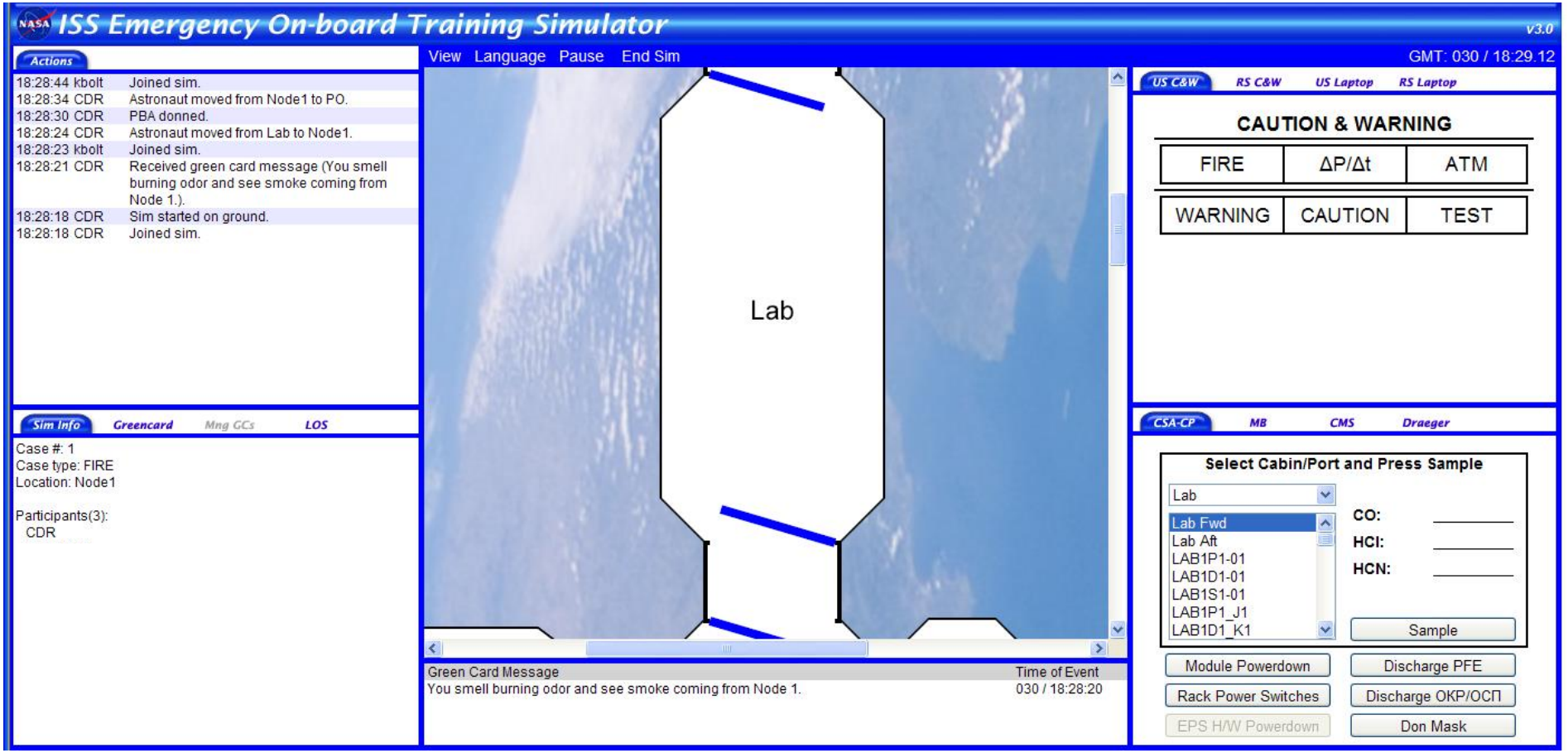
RS Laptop with ИП Resolution capability

Dynamic MB: (Will adjust drop rate based on hatch closures)

Crew Interface – Ammonia Leak Scenario



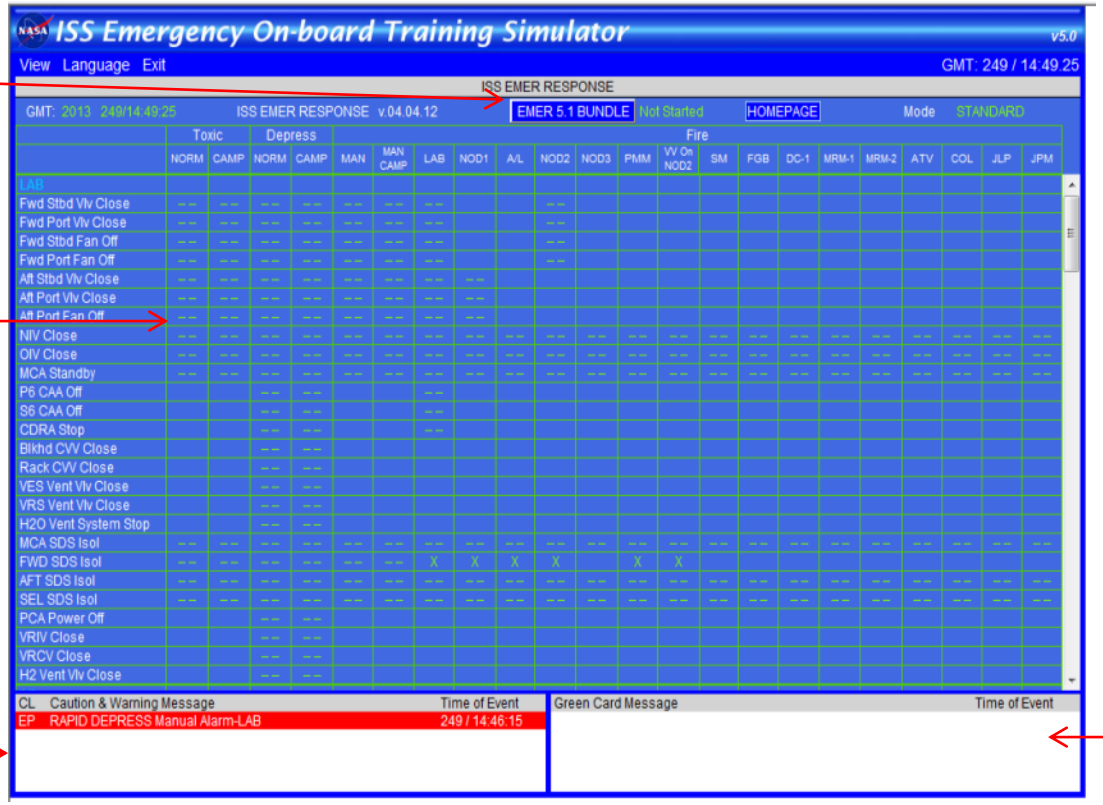
Instructor Interface



Flight Controller Interface – Example
ISS Emergency Response Telemetry Display

•Raised button icons denote command capability

•Data changes based on EMER autoresponse actions for each type of emergency

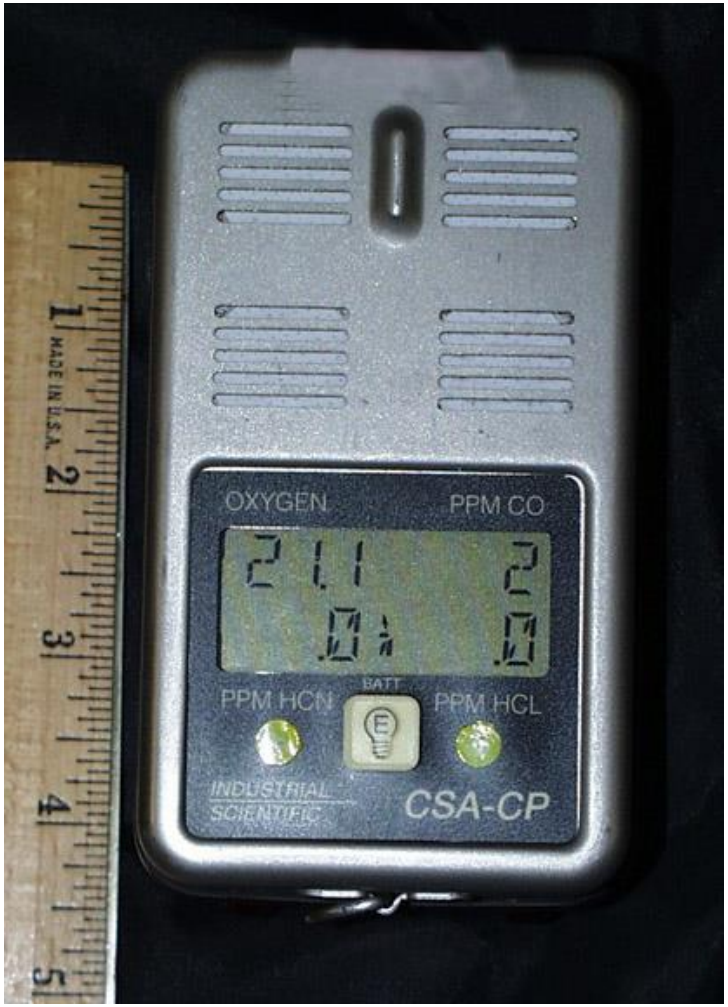


•C&W Summary

•Real-time greencards

Synergy and Leveraged Codebase

- The Emergency OBT Simulator codebase contained the structure and means for another separate application
  - Compound Specific Analyzer for Combustion Products (CSA-CP) is a handheld device used by crew to “sniff-out” potential fire sources, even behind rack panels via “fireports” using a sample pump and probe assembly



Synergy and Leveraged Codebase

- Previous ground training methods were somewhat ineffective and potential sources of negative training
  - Verbal “greencards” did not force crew to look at the device for readings and allowed for other crewmembers to eavesdrop and listen-in to the readings from the instructor
    - Broke the desired critical data communication path between crew
  - Visual “greencards” were an improvement over the former, but did not realistically display the information
    - A lesson-learned from a false fire event on-orbit showed that crew could easily overlook decimal points as there is no leading zero for some contaminant values
    - This also forced instructors to be in the modules with crew, which is not desired

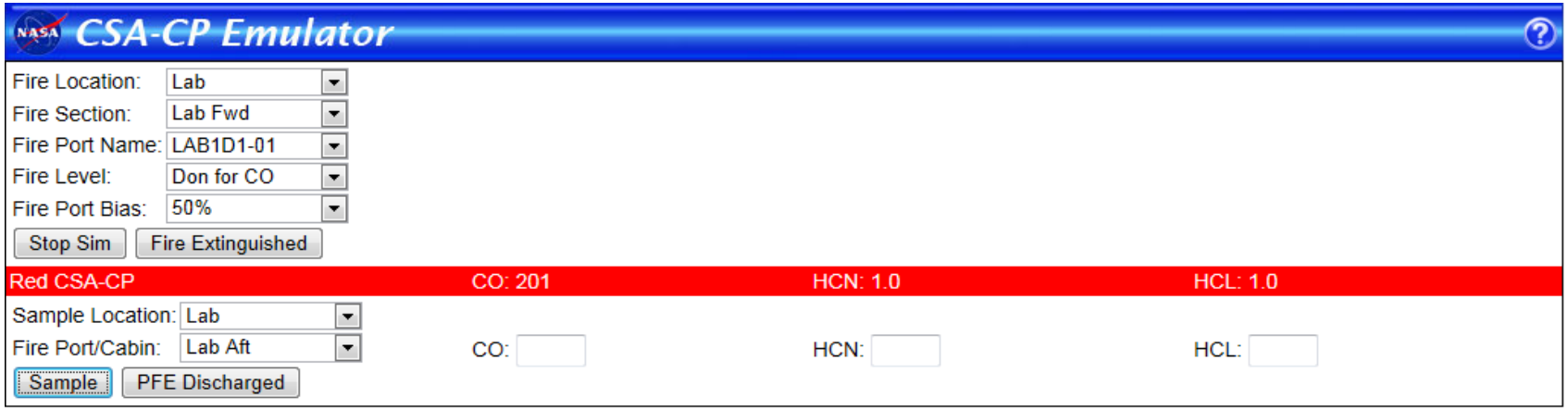
Verbal and Visual “Greencards”

CSA-CP Emulator

- Utilizes the fire contaminants model codebase from the Emergency OBT Simulator to generate appropriate CSA-CP values
  - Some custom GUIs and small code additions to drive them
- Crew view accessed via web browser on iPod Touches
  - Attaches to flight-like CSA-CP unit for use in training scenarios
  - Crew iPods are color-coded for easy visual identification
- Instructor view accessed via web browser on Instructor iPad
  - Input key telemetry items for desired case objectives
    - Fire location
    - Initial contaminant levels and rate of increase of contaminants
      - Ten “fire levels” available to train all potential objectives
      - Custom data can also be pushed to the crew units
    - Fire extinguishing method
  - Instructor GUI controls what data, i.e. which module or fireport, each crew unit should display

CSA-CP Emulator

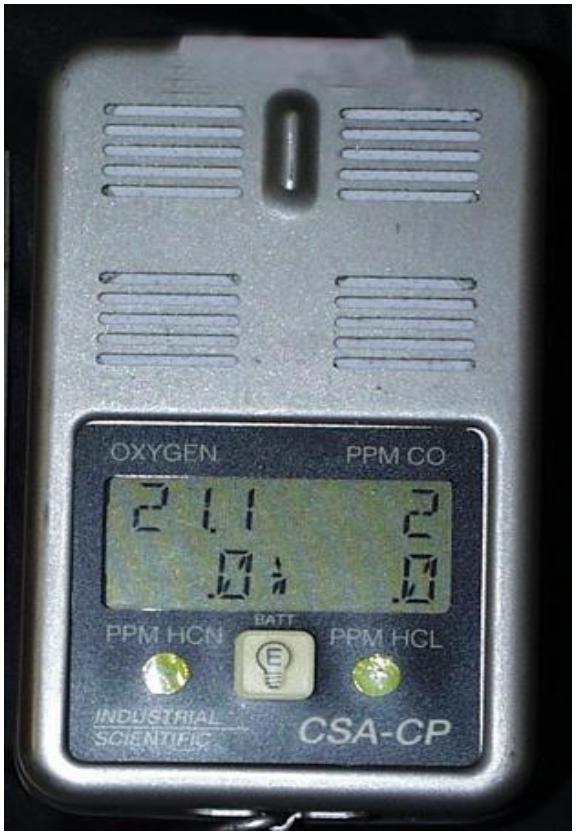
- Instructor interface



CSA-CP Emulator

- Crew view
  - Flight-like size and display on iPod

Flight Unit



Risk Reduction Conclusions

- Safety is paramount to the JSC mission, and the ISS Emergency OBT Simulator reduces risk by increasing preparedness and improving OBT training quality for the crew and the flight control teams
  - ISS is large and complex, and urgent events require a swift and coordinated response by crew and ground
  - All participants engage, adjust and learn as the case unfolds real-time
- By leveraging an existing codebase to a new synergistic platform using COTS hardware, CSA-CP ground training quality was also drastically improved, further reducing risk for fire response onboard ISS

Questions?

Backup Slides - Timeline

- 2010 – Discussions on early concepts of Emer OBT simulator design
- 2011 – Requirements document signed
- Nov 2011 – OBT simulator V1.0
- June 2012 – OBT simulator V2.0
- July 2012 – First On-Board Depress drill, OBT simulator V2.2, First On-board Fire drill
- Sept 2012 – First Ground and On-board Synchronized Depress drill with Ku-band
- Nov 2012 – OBT simulator V2.3, First back-to-back OBT drills
- Jan 2013 – OBT simulator V3.0, First Russian Fire drill
- Jan 2014 – Discussions on early concepts of CSA-CP Emulator design
- Jan 2015 – First use of CSA-CP Emulator in ground crew training

Backup Slides – Technical Details

- Web application
  - Code executes on Windows PCs using Internet Explorer 8.0 or Apple iPads using Safari
  - 91 KSLOC (in .cs, .aspx, .js, .css, .xml, .xsd files)
- On-board Station Support Computer Server allows multi-player access for crews in different locations to perform actions
- Ground Server allows simultaneous access for teams in different locations
  - ~50+ Flight Controller and Instructor participants in Houston, Moscow, Huntsville, Munich, Tsukuba and any other center participating in Ops that day
- Synchronized by transferring XML state files between servers over Ku-Band using Orbital Communications Adapter Mirroring System (OCAMS) scripts
  - Graphical user interfaces use a combination of Web Forms and Scalable Vector Graphics (SVG) and are dynamically updated using JavaScript and jQuery
  - Data downlinked about 2 times per minute (avg file size ~145kb)