On-Orbit Leak Detection and Repair for International Space Station

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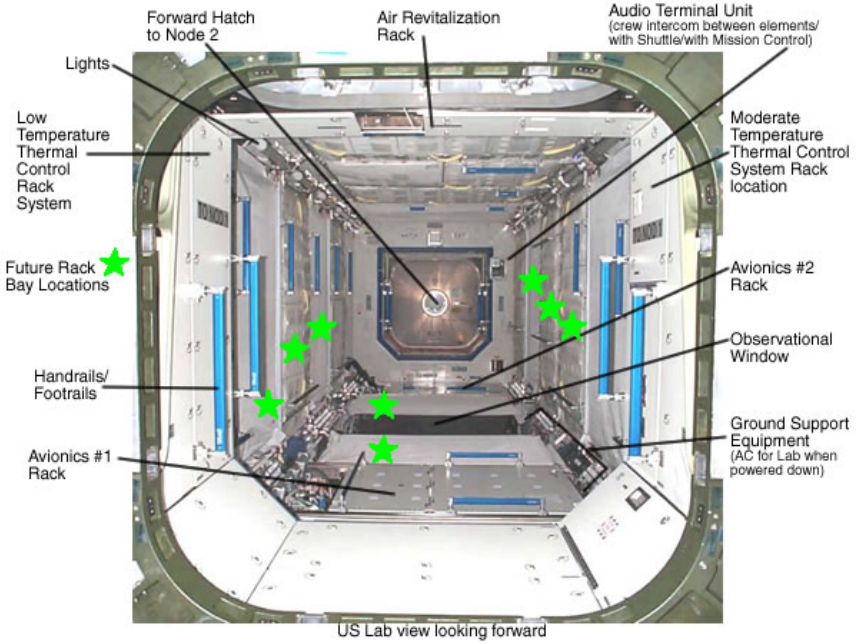
The Space Station Need

The International Space Station (ISS) is built with a large percentage of its hardware initially designed and developed for the Space Station Freedom program. Due to the smaller size of the Freedom Station and new module designs incorporating a robust orbital debris protection system, the probability of penetration by meteoroids or orbital debris was sufficiently low to mitigate the threat of pressure wall penetration that led to the decision to not implement a pressure wall penetration / leak location system.

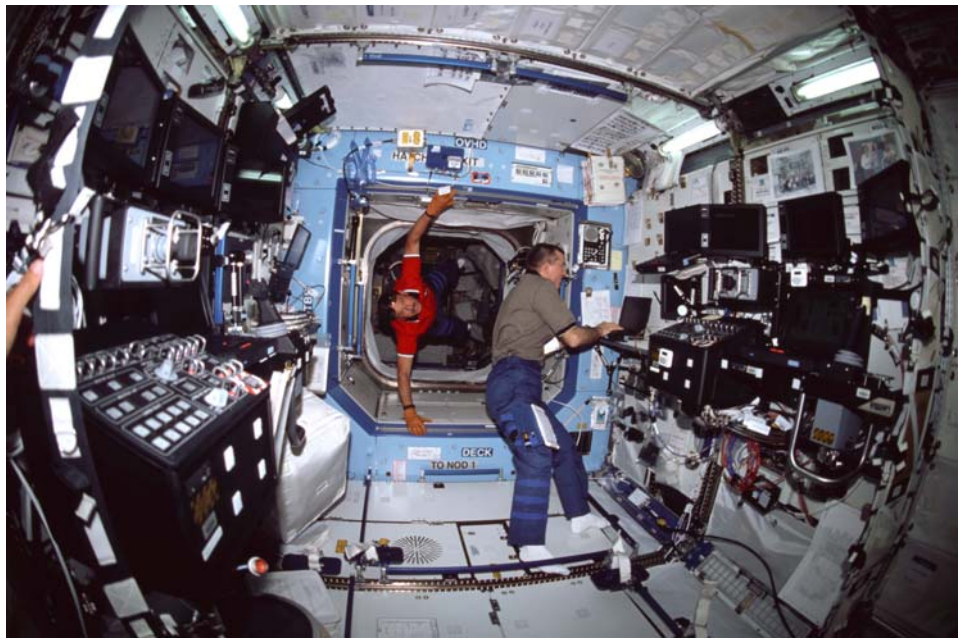
When the Space Station Freedom program transitioned to ISS and added Russian modules – increasing vehicle size and adding early capabilities from Russian space station experiences, the probability of penetration from debris impact rose sufficiently to necessitate developing and retrofitting a leak location system.

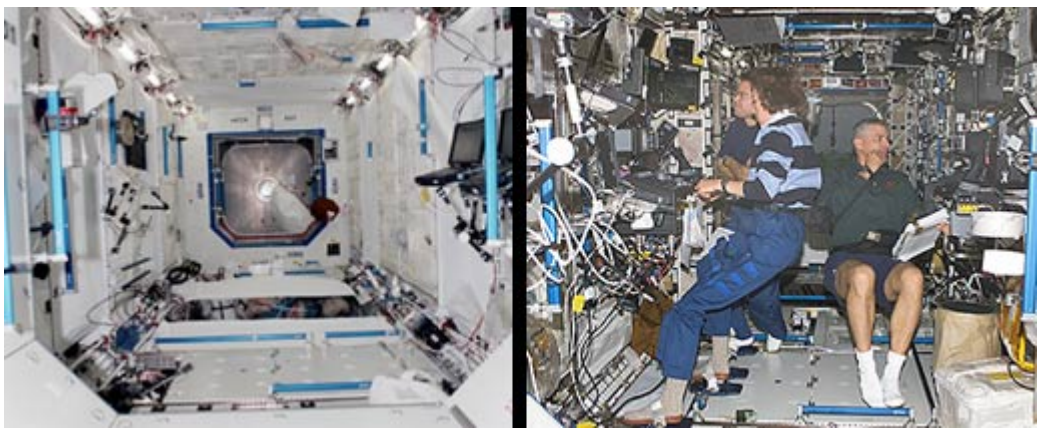
The Space Station Need

pictorially – US Lab

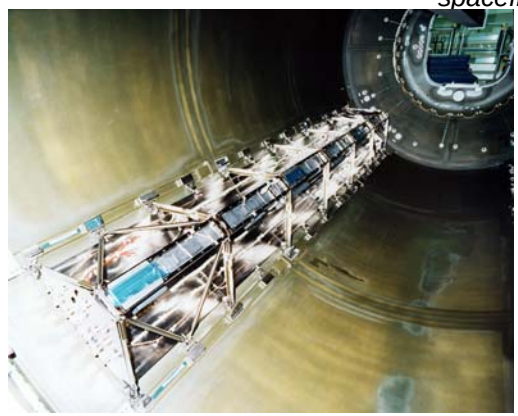


http://www.boeing.com/defense-space/space/spacestation/gallery/spcst413.html





spaceflight.nasa.gov



http://www.nasa.gov/mission_pages/station/structure/elements/destiny.html

The Space Station Need

pictorially – Service Module

ISS013E82952

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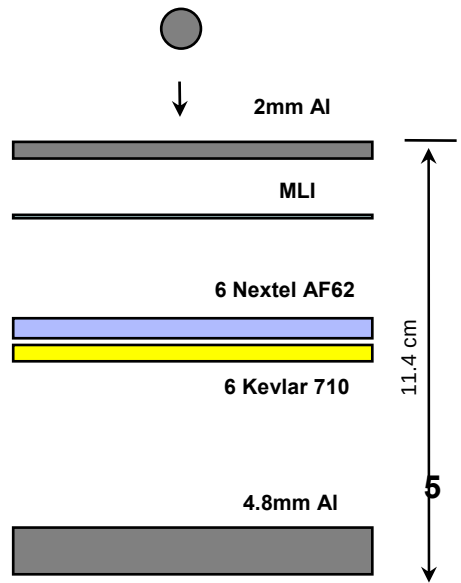
Imagery from spaceflight.nasa.gov

Meteoroid / Orbital Debris Protection Approach

- Multi-faceted approach to mitigating MMOD Risk on ISS
  1. Robust shielding
  - **ISS has best shielding ever flown: US/ESA/Japan Nextel/Kevlar "stuffed" Whipple shields effective for 1.3cm diameter debris impacting at typical impact conditions**
  - **Redundant & hardened external systems; e.g. US Radiators**
  2. Collision avoidance
  - **Maneuver to avoid ground trackable orbital debris (typically ≥ 10cm diameter)**
  3. Sensors & crew response to leak if needed
  - **Leak detection, isolation, repair**

0.5" diameter hypervelocity projectile penetrates nearly 2" thick aluminum block, but is stopped by NASA stuffed Whipple shields which weigh far less (same as 3/8" thick aluminum)



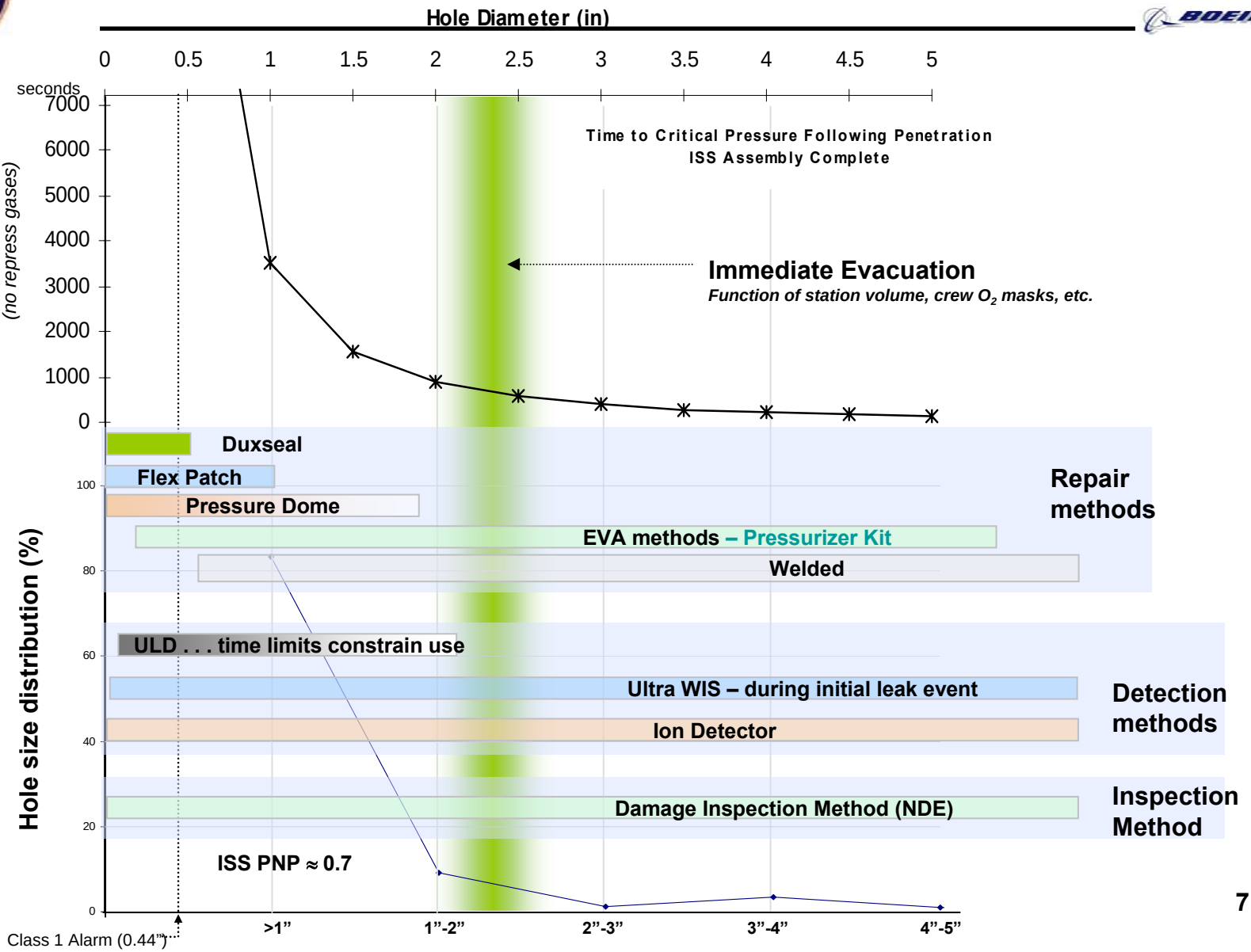
Leak Detection and Repair Project Overview

In case of an atmospheric leak from the ISS pressurized modules the following systems are needed for the location of the leak and repair the pressure shell on-orbit

- **Detection methods**
  - **Pressure sensors to detect the atmospheric leak**
    - **Software to compute the leak rate**
    - **Software to compute the remaining time to compartment evacuation**
      - » **This enables the decision for immediate compartment isolation or IVA repair**
      - » **If the compartment had to be evacuated and isolated the subsequent repair has to be performed EVA**
    - **Existing ECLSS sensors**
  - **Leak location sensors (Under development)**
    - **Determine which pressurized element is leaking**
    - **Determine where the leak is located on the pressure wall of that element**
- **Inspection methods (Under development)**
  - **To determine the extent of damage**
- **Repair methods to repair the pressure shell IVA or EVA (Under development)**
  - **Pressure integrity restoration**
  - **Structural integrity restoration may also be required**

Leak Detection and Repair Project Overview

graphically

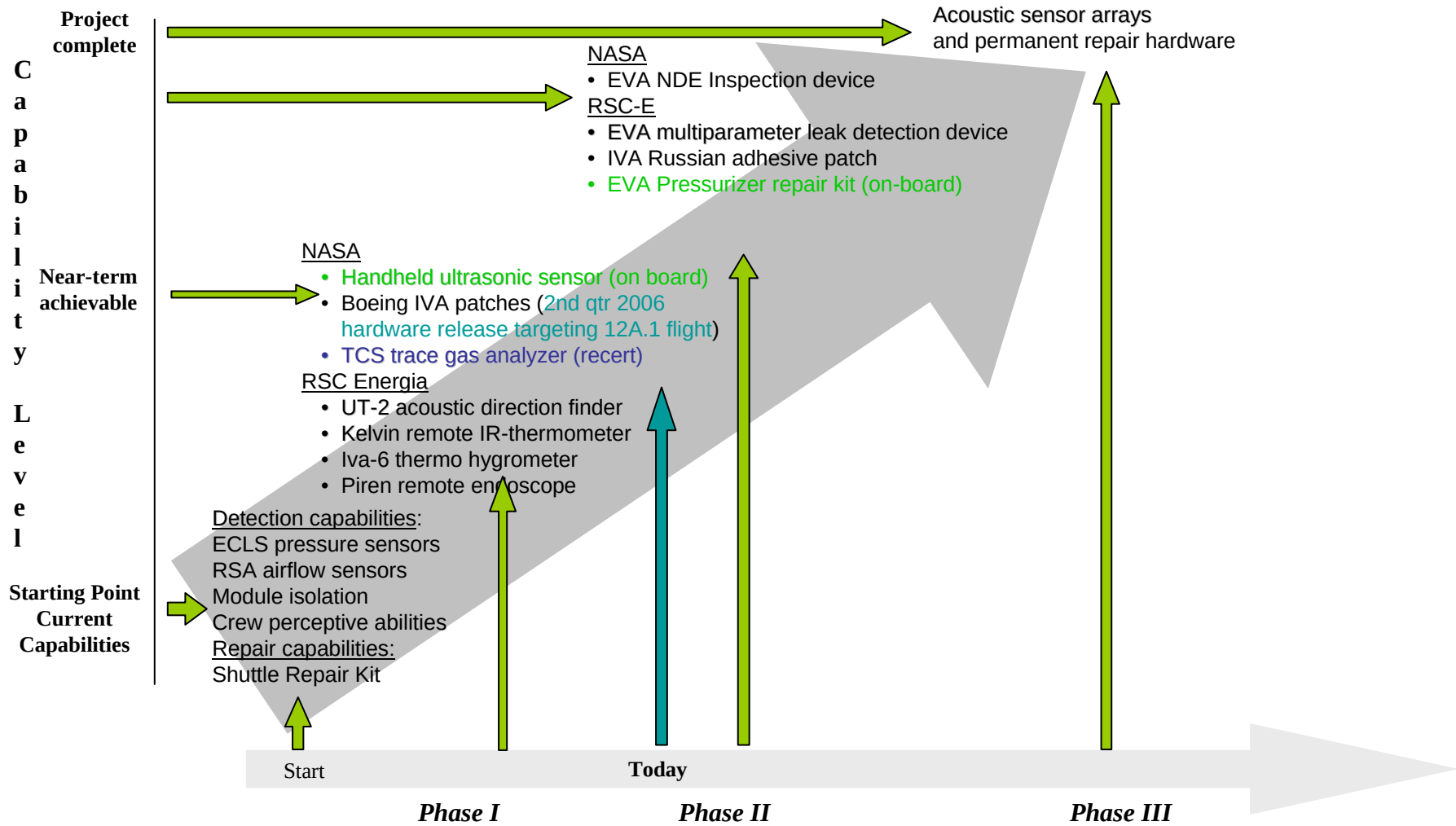


Background

- On-Orbit Leak Detection and Repair Panel developed 3 phase approach for ISS leak detection and repair
- Approved April 2001 Joint Program Review, Moscow
  - Phase I - existing hardware, temporary leak detection and repair hardware
    - Provide existing Russian and US leak detection and temporary repair kits
    - Complete and release Leak Detection and Repair Requirements Document
  - Phase II - existing design, temporary leak detection and repair hardware
    - Complete and provide hardware currently under development
      - EVA/IVA temporary repair hardware
      - EVA leak detection / location hardware
      - Structural Damage Inspection hardware
  - Phase III - new design, permanent leak detection and repair
    - Complete design and development of acoustic sensor arrays and permanent repair hardware

Three Phase Implementation

graphically



Implementation Plan

- Phased implementation
- Utilize existing hardware as much as possible
- Provide a single solution to leak detection, leakage location, leakage source characteristic identification, leakage repair, structural repair, and leakage repair certification system for all of the International Space Station (ISS) on-orbit needs
- Provide the on-orbit ability to:
  - Rapidly detect off nominal leakage from pressurized modules
  - Provide rate information of atmospheric leakage from pressurized modules
  - Provide location information of the leakage source
  - Characterize the leakage source, location, and degree of damage
  - Provide repair kits and equipment for restoration of structural and pressure integrity
  - Certify the leak has been repaired

Current Status

- **On-board**
  - Ultrasonic Leak Detector
  - Aluminum sheet metal
  - Gray Tape
  - Russian Pressurizer kit
    - EVA epoxy repair kit for DTO on-orbit
  - Germetal Epoxy
    - 2-component epoxy for IVA repairs
  - 1 lb. Duxseal
- **Pending**
  - IVA repair kit *(2nd quarter '06 to NASA)* ⟵ *Now on-board*
  - BAR sensor set flight experiment
  - Fiberscope manifested on ULF1.1 ⟵ *Now on-board*
- **Under development**
  - Location sensor system
  - Damage inspection system
  - EVA repair methods
  - Structural integrity restoration methods
- **Crew training**

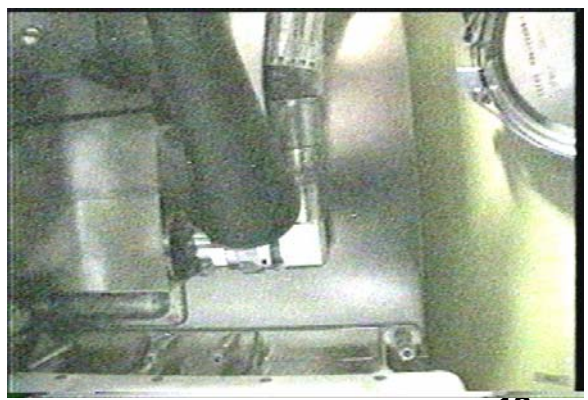
Current Status

pictorially

IVA Leak Detection / Location Hardware

Handheld Ultrasonic Leak Detector (ULD)

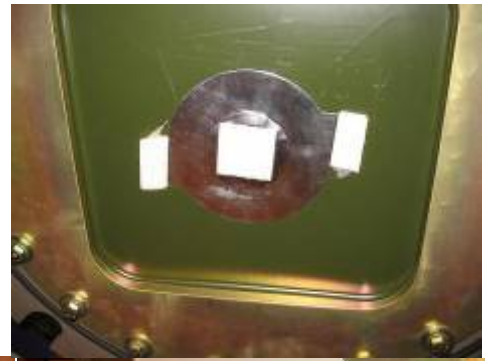
- **On-board**
- **Used for locating Airlock valve leak**
- **Used in flex hose leak location**
- **Adapted COTS hardware**



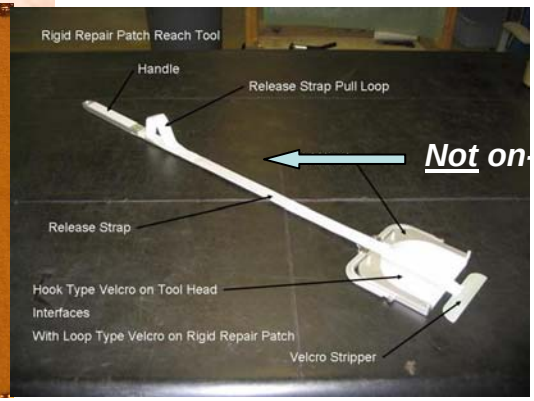
Current Status

pictorially

- **IVA Adhesive patch**
  - **Successful development, qualification and acceptance tests with delivery to NASA during 2nd quarter 2006**
- **Small Pressure Dome**
  - **Successful development, qualification and acceptance tests with delivery to NASA during 2nd quarter 2006**
- **Enhanced Shuttle Kit**
  - **Hardware On-Orbit**



***Now* on-board**



***Not* on-board**

Current Status

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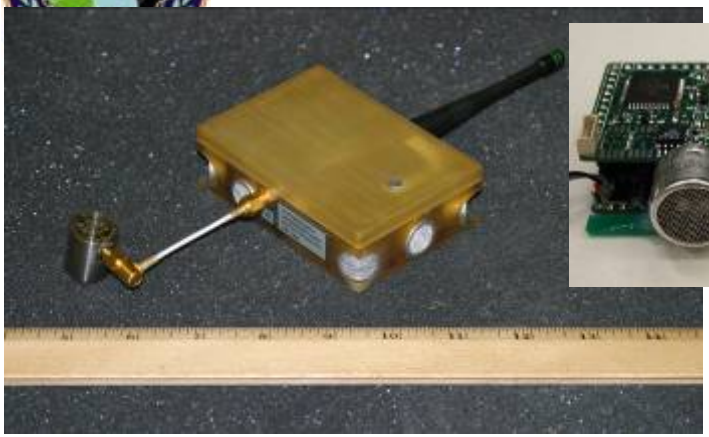


- **Ultrasonic sensor (Internal)**
  - **Impact Sensor wakes up Acoustic Leak Location System**

- **Rarefied atmosphere sensor (external)**
  - **Mir flight experience**
  - **Scalar quantity of molecules**

On-board

- **ISS Fiberscope Kit**
  - **Separate development by Crew and Thermal Systems**
  - **Manifested for ULF1.1**

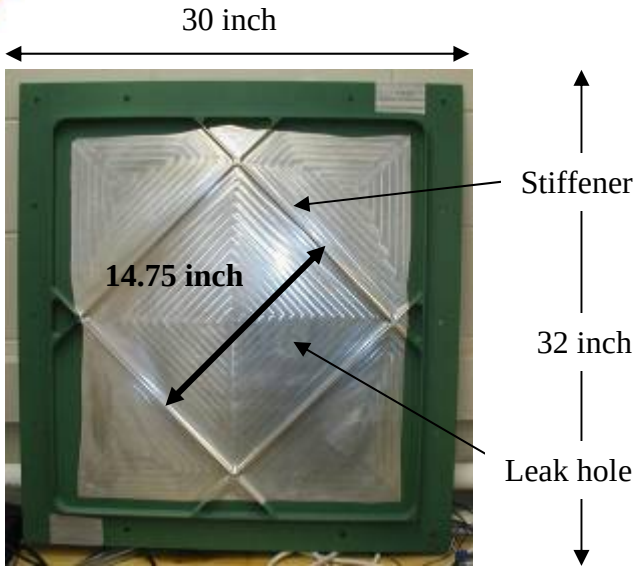
Current Status
Leak Response Procedure Overview / Crew Training

1. Assemble at Soyuz.
2. Determine whether leak is in Soyuz or elsewhere.
3. Obtain leak rate data.
4. a. If Soyuz, make determination regarding isolating Soyuz or entering and emergency evacuation.
4. b. If not Soyuz, make determination regarding emergency evacuation or attempting isolation and/or repair.
5. Follow emergency response procedure to systematically close hatches in predetermined order to determine which module is leaking and isolate it.
6. Obtain ISS Leak Kit containing hard copy procedures, ULD and Leak Repair materials.
7. Based on available remaining time before mandatory evacuation, systematically inspect suspected areas for leak. ULD may be used at this time to assist in pinpointing leak location.
8. Determine appropriate patching method based on leak geometry and location. If time permits, take a picture of hole.
9. Install patch to stop leak.

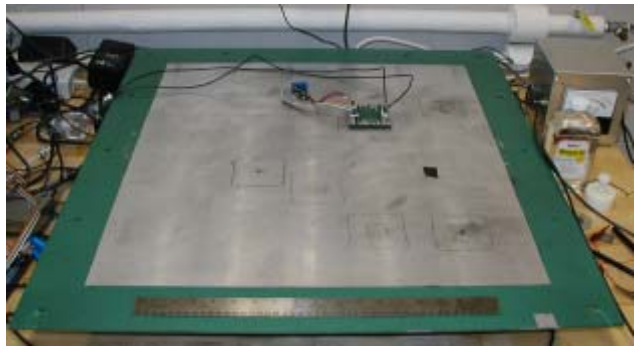
Periodically reviewed and revised.

Current Status

pictorially

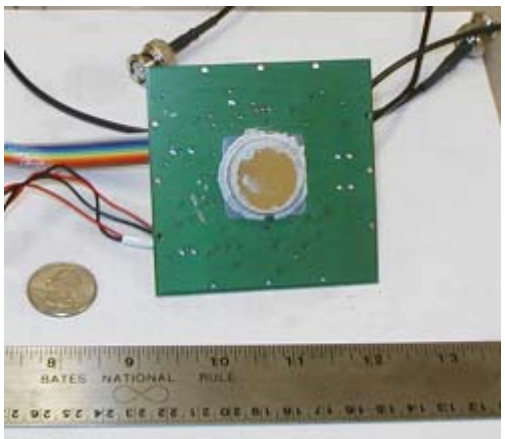


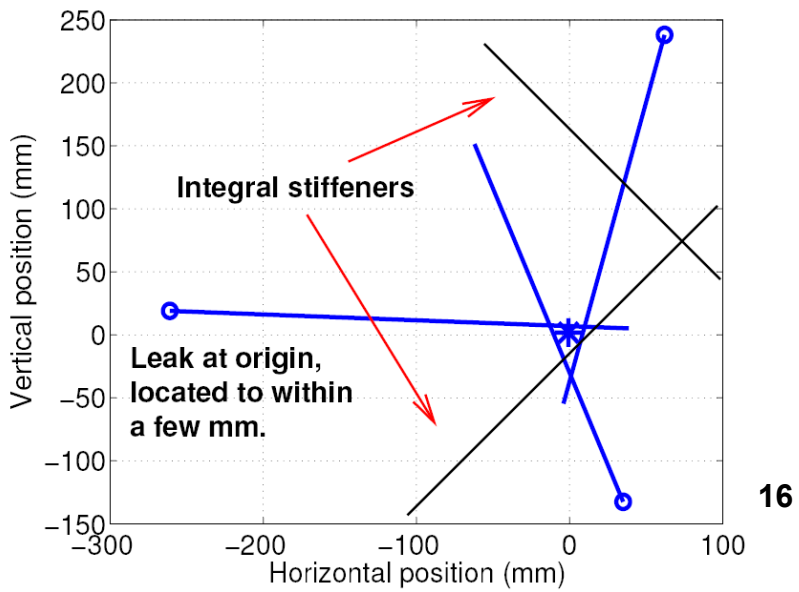
Space Station test panel, 1/8 inch thick skin, 1 inch tall stiffeners



- Located leak within few mm
- Performed robustly across stiffeners

Completed assembly of prototype array receiver





Summary

MMOD protection strategy enacted at ISS inception is in place

- ✓ **Identify and control catastrophic hazards to extent possible at initial item launch**
  - ✓ **Designed, built, and installed for US, Japanese, European, and most Russian modules**
  - ✓ **Establish and enact plans for protecting assets not shieldable in initial launch configuration (EVA installed shields)**
- ✓ **Perform collision avoidance maneuvers as warranted for tracked objects**
- ✓ **Identify and protect mission-critical hardware**
- ✓ **Develop means to enable crew to locate and repair small holes**
- ✓ **Perform initial development on EVA location and repair methods**