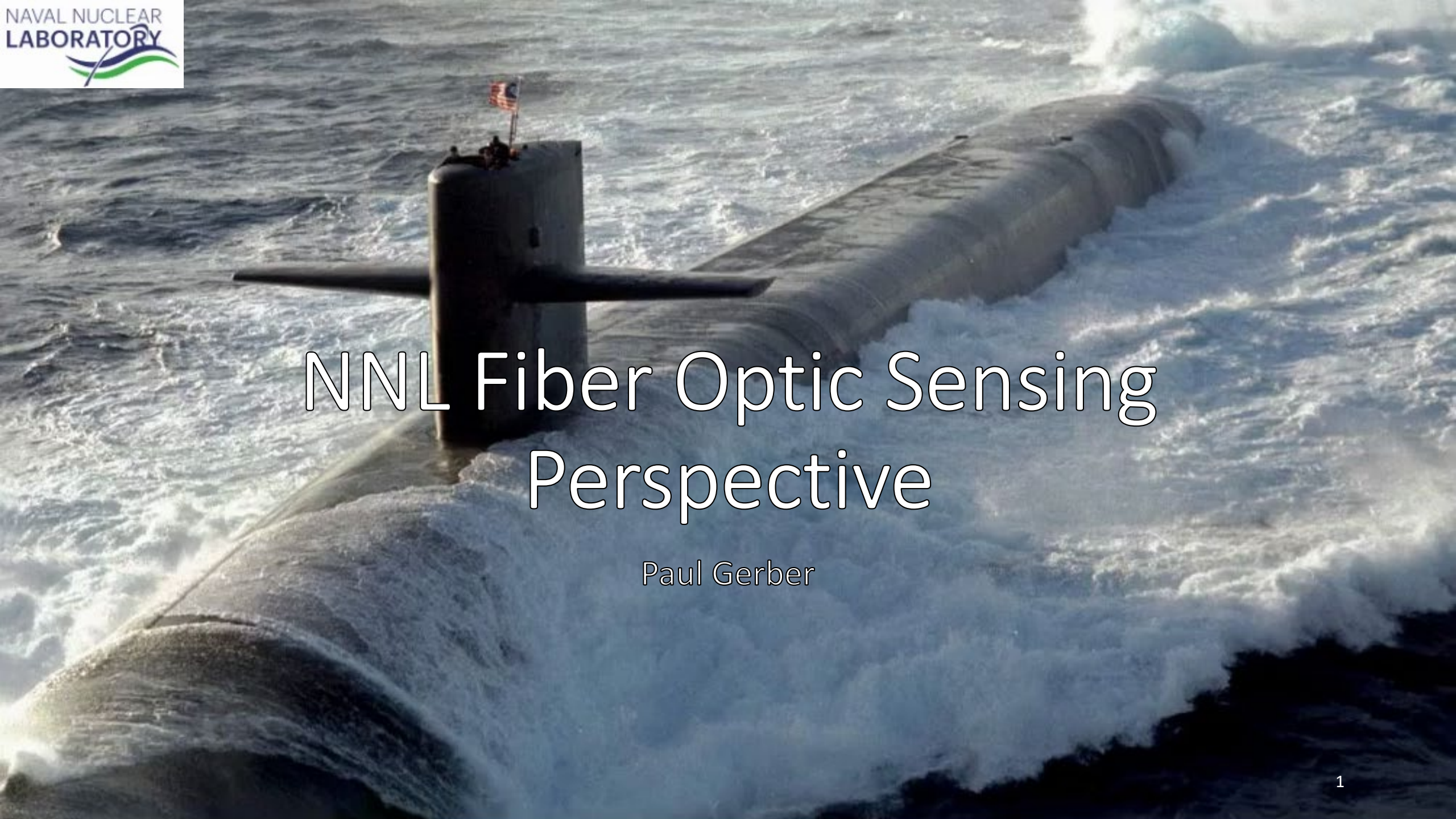


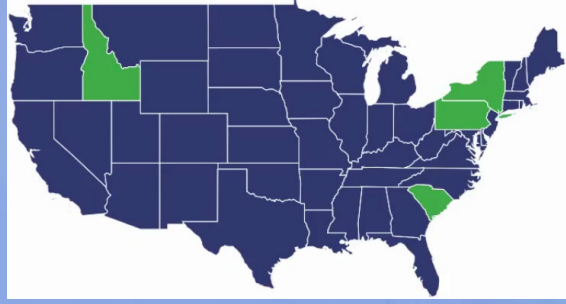
NNL Fiber Optic Sensing Perspective

Paul Gerber

Agenda

- About NNL
- Conditions
- Brief history fiber optic sensing at NNL
- Potential applications
- Challenges
- Conclusion

About NNL

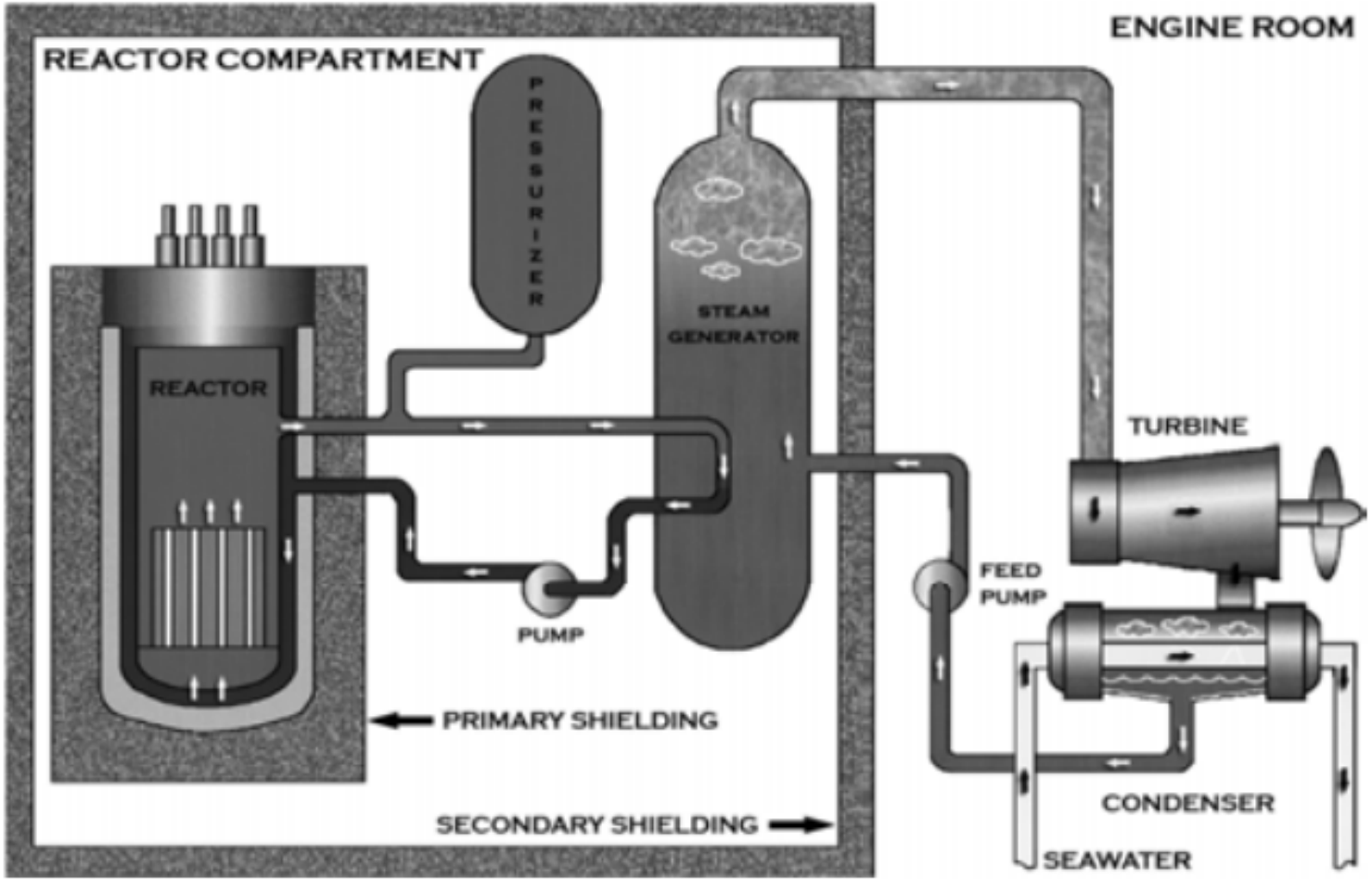


- Develop advanced Naval Nuclear Propulsion technology
  - Ensuring safety and reliable operations of reactors
- Train the sailors who operate our reactors
- Full life cycle support

- Supporting the Navy since 1948
  - Knolls Atomic Power Laboratory-Schenectady, NY
  - Kenneth A. Kesselring Site-West Milton, NY
  - Bettis Atomic Power Laboratory-West Mifflin, PA
  - Nuclear Power Training Unit (NTPU) Charleston Facility-SC
  - Naval Reactors Facility (NRF)-Idaho Falls, ID

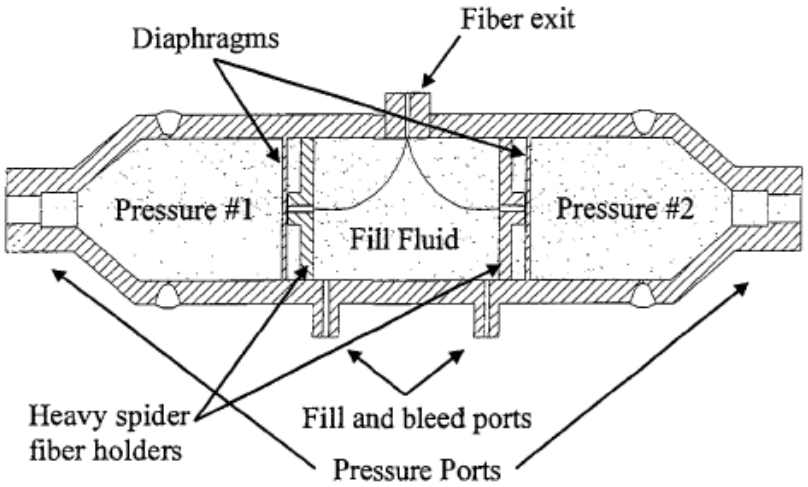
Conditions

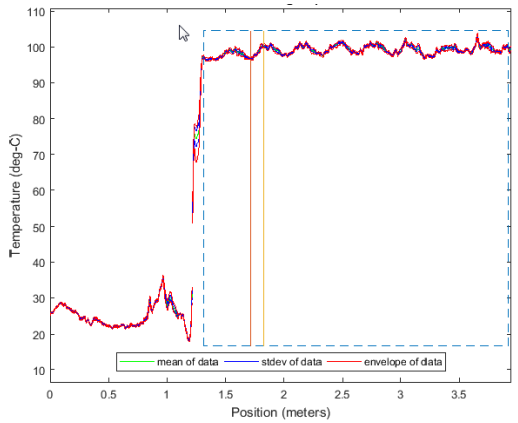
- Uses throughout ship
- Harsh environment in the reactor compartment
- Temperature
  - 20°C to 800°C
- Radiation environment
  - 10 Mrad gamma exposure
  - Fluences ranging from 1 to $4x10^{21}$ n/cm^2 (fast)

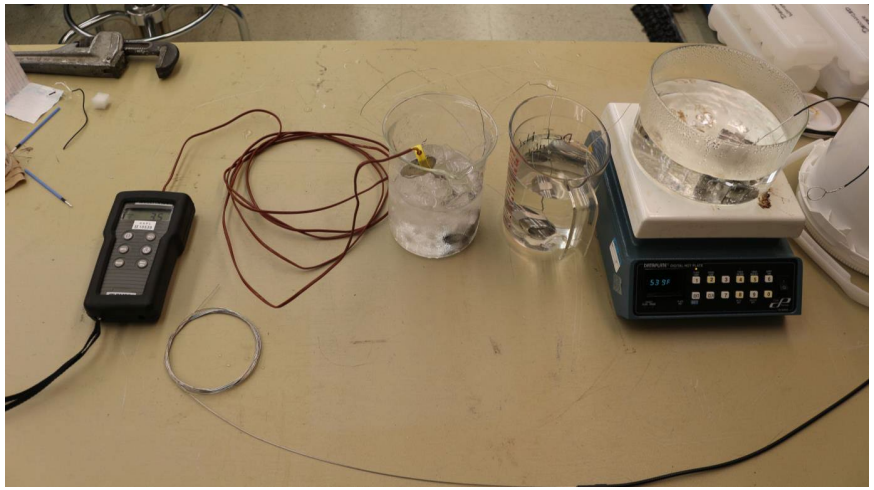


Brief History Fiber Optic Sensing at NNL

- 1990's to early 2000's
  - Differential pressure sensor – Fabry-Perot
    - Temperature sensor for compensation
  - Raman spectroscopy and fiber visualization system
    - Multi-mode, Germanium doped fiber
    - Large radiation induced attenuation
  - Perform radiation testing of optical fibers
    - Performance varied between vendors
    - Pure silica cores worked well
- 2010's temperature and pressure
  - Revisited differential pressure sensor
  - 2016 used fiber Bragg grating system to measure temperatures of a motor
- 2017 started current efforts
  - Verification testing
  - Radiation testing of optical fibers
  - Shipboard testing

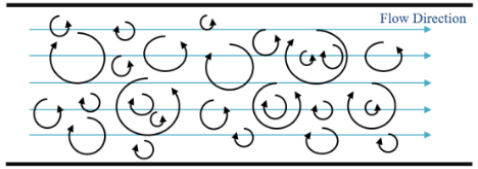


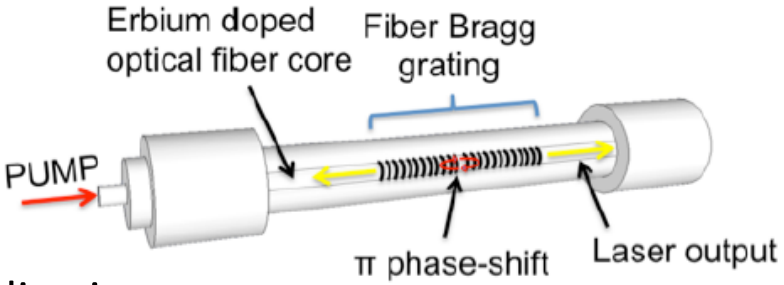


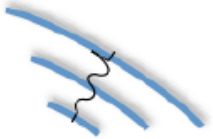


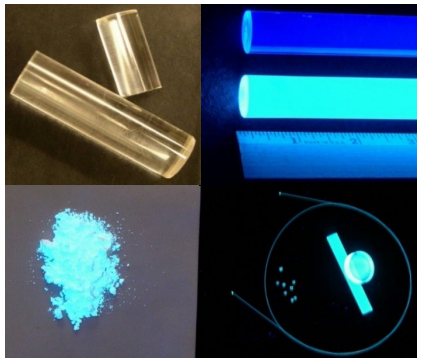
Potential Applications

- Temperature Sensing
  - Piping, components, internal fluid, and in-pile
- Fire detection system
- Flow measurements
- Structural health monitoring and condition based maintenance
- Acoustics
- Pressure measurement
- Automation to reduce maintenance cost
- Position sensing and shape sensing
  - Structural deformation, load monitoring, and spatial localization
- Distributed electromagnetic sensing
- Dosimetry - total dose and dose rate
- Corrosion
- Chemical identification in coolant sampling
- Embedding sensors
- Model validation and digital twinning









Challenges for Shipboard Implementation

- Laboratory and shipboard testing viable
- Challenges is for permanent shipboard applications
  - Finding the right application(s)
  - Integration with ship systems
  - Miniaturizing interrogator to fit on card
    - Many methods for implementing fiber optic sensing
      - Use methods that cover largest range of applications
  - Qualification of system
  - Lower cost
  - Reactor compartment environment
    - Coating issues due to combination of temperature and radiation
    - Longevity of sensor
    - Enhanced Rayleigh and fiber Bragg gratings
      - Not readily available in radiation hardened fiber
      - Limited coating types
    - Temperature limitation with using plastic scintillation fiber
  - Intellectual property concerns
  - Fighting perception of cost and new technology
  - Large data set concerns

Conclusion

- High interest
- Plenty of potential applications
  - Offer step change in measurement capabilities
  - Offers innovative solutions
  - Reduce work force effort and cost
  - Improve performance
- Need a good short-term application
- Coming through challenges for permanent application
- We need to collaborate together to ensure we can deliver products to the Navy