Selection of Materials for High Reliability Subsea Applications & High Power

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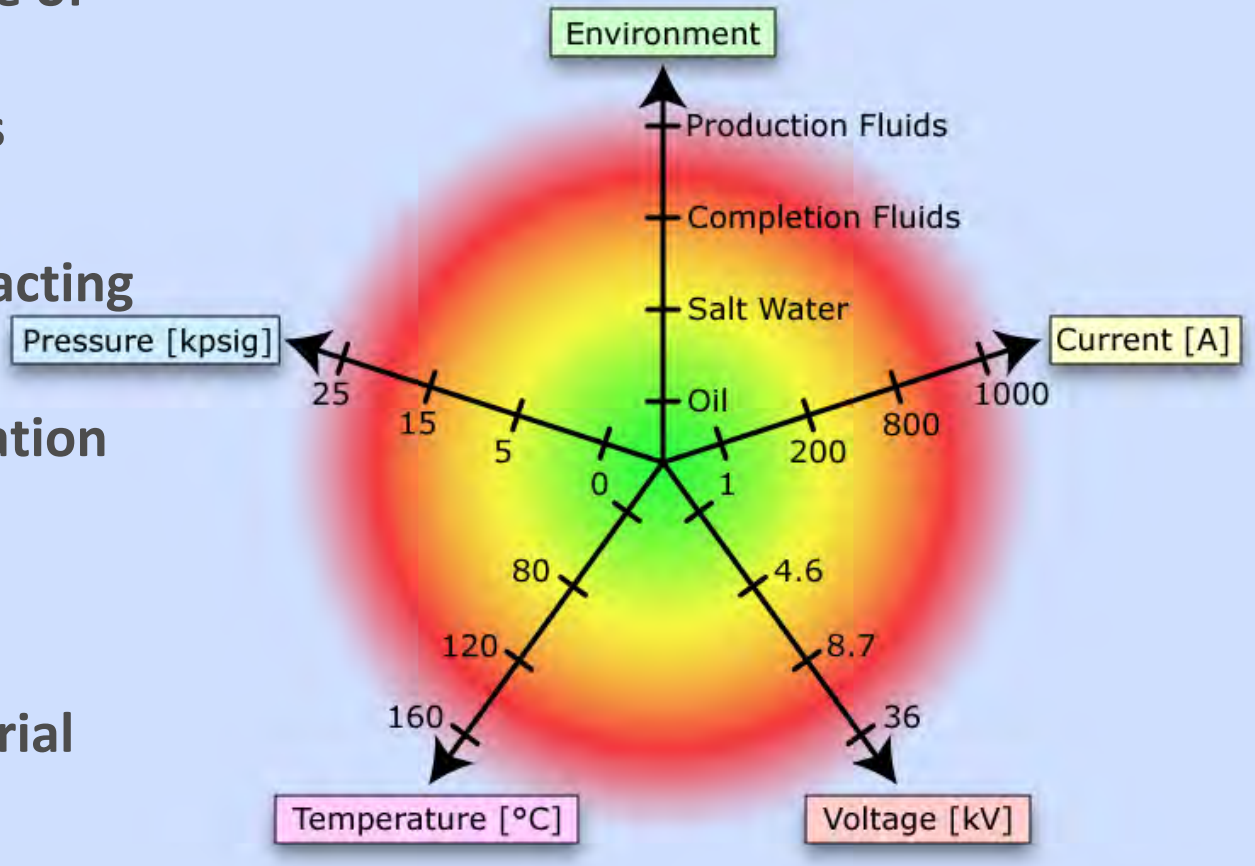
Increasing Demands on Materials

- New HP subsea systems deployed in deeper water, requiring more power and operating at higher temperatures
- In-depth knowledge of physical material behavior is needed to predict End-of-Life-Performance
- Develop a proprietary materials database and selection tools to minimize product risk and development risk

Develop superior products in shorter time

Multi-Stress Universe

- Detailed knowledge of use environment is critical to materials selection
- Multiple stressors acting simultaneously
- Synergistic degradation mechanisms
- Sequential testing is not sufficient to determine material properties



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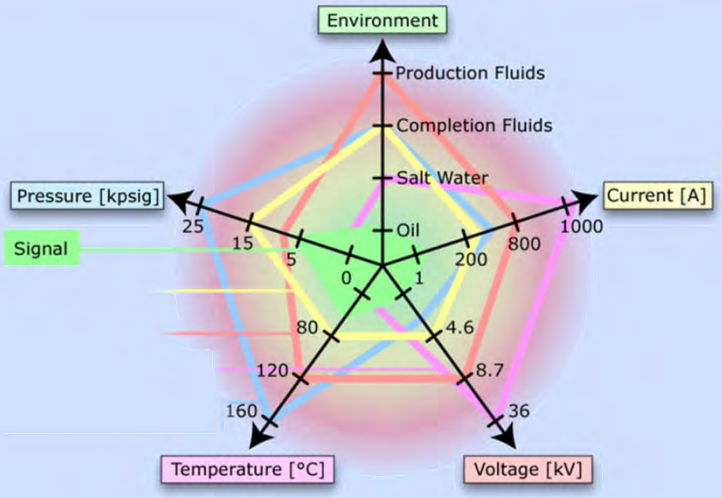
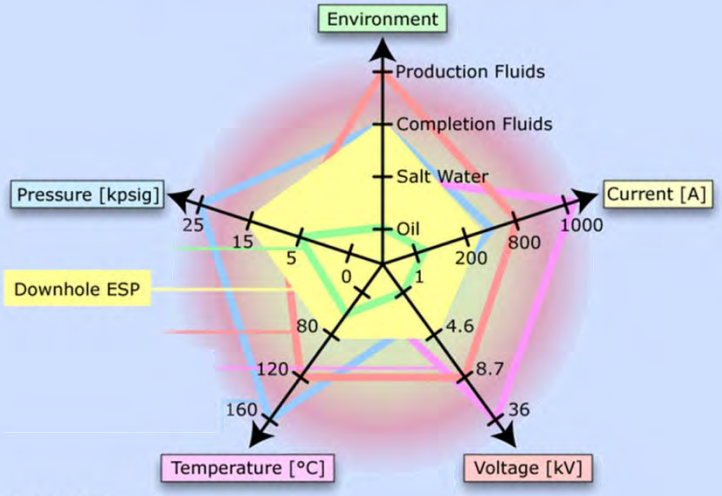
Notional Projects





- **Examples of environments on several typical connector applications**
- **Dry-mate low-voltage signal connector**
  - Well controlled chemical environment
  - Low stress on materials overall
- **Wet-mate medium voltage connector/penetrator through tubing hanger for ESPs**
  - Chemical stress due to completion fluids
  - Elevated temperatures and pressure
  - High electrical power requirements

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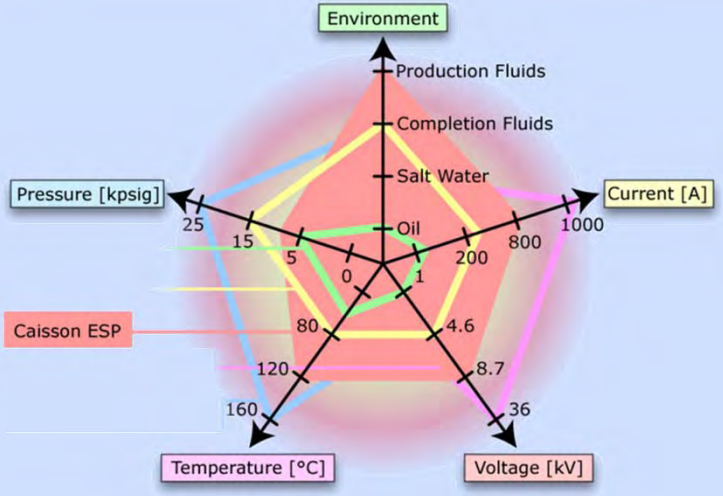
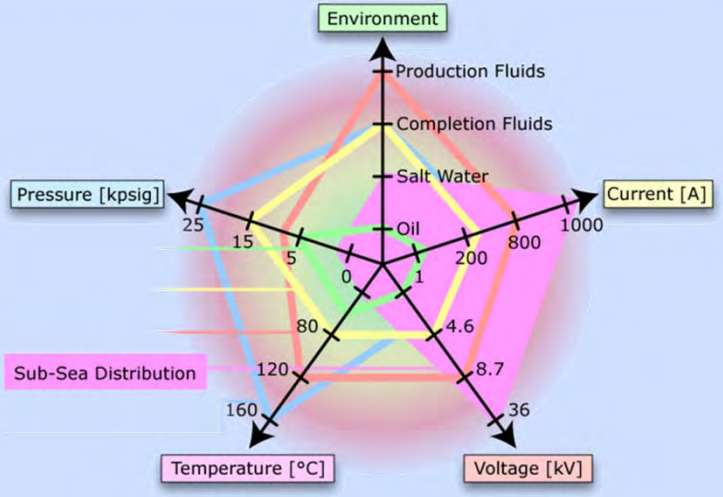
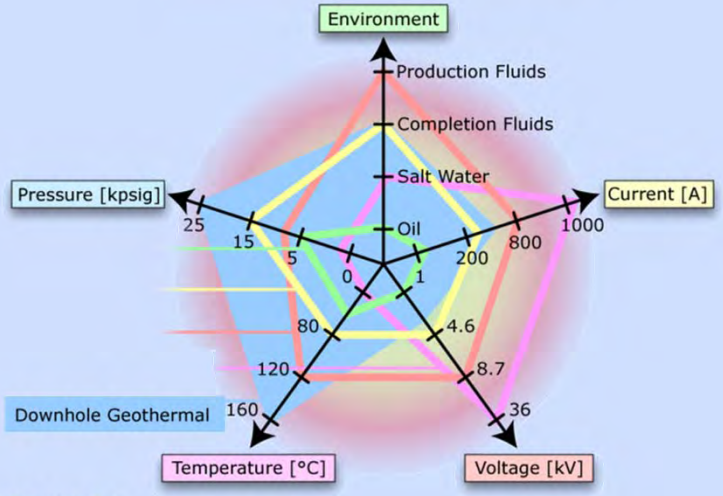
Notional Projects







- **Other challenging applications clockwise from top-left**
  - Caisson ESP feed-through due to chemical environment
  - Sub-sea electrical sub-station connector due to high-voltage
  - Hot-rock downhole geo-thermal penetrator due to thermo-mechanical environment
- **No single material can satisfy all environments**

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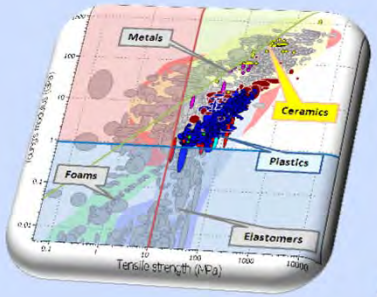
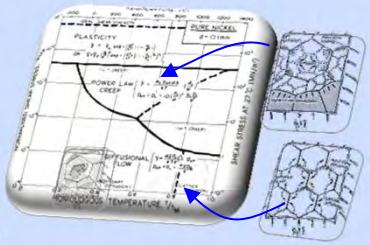
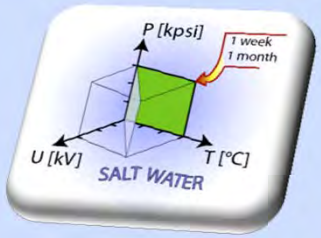
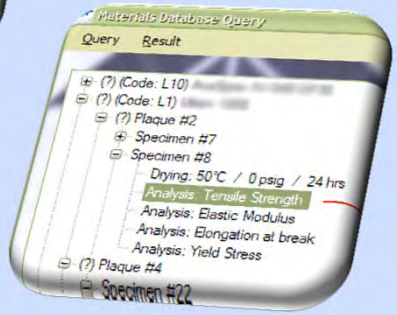
Materials Selection & Reliability Assurance

- Establish a fully searchable proprietary materials database and materials selection & reliability tools
- Develop technical standards & test methods for materials subjected to multiple stress conditions
- Determine critical life-limiting degradation mechanisms to reduce risk in new products
- Identify robust materials for long term reliability (>25 year) under severe subsea conditions









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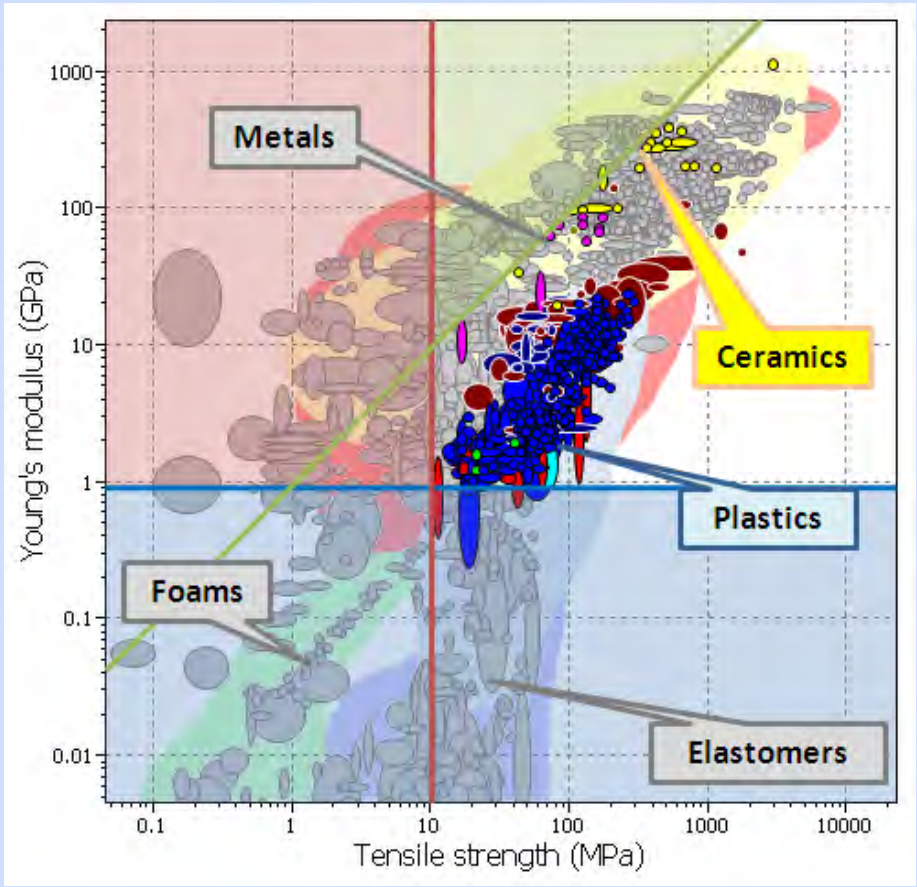
Materials Selection

- Identify key performance requirements & properties that govern performance
- Define design space (satisfy-able operating conditions for best suited materials)
- Rank materials classes & individual materials based on key properties

Need to be based on predicted End-of-Life-Performance



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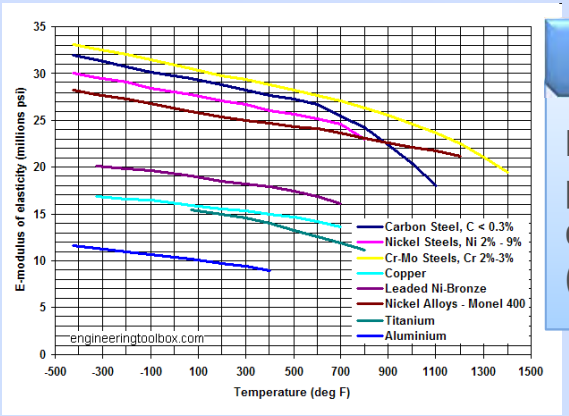
Understand Environmental Effects

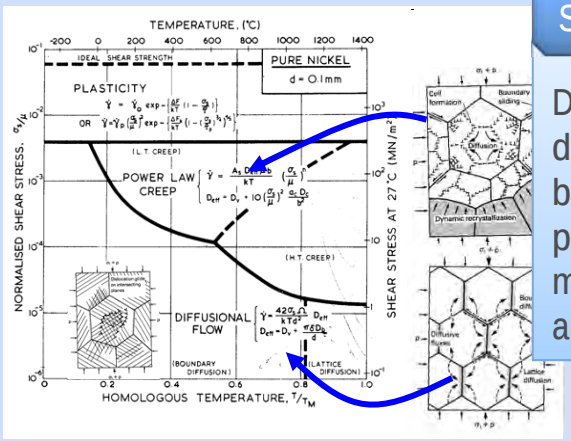


Collect material data

Measure the materials properties as function of the environment (time, temp., pressure)

Screen Materials

Use material property data and environment data to screen materials

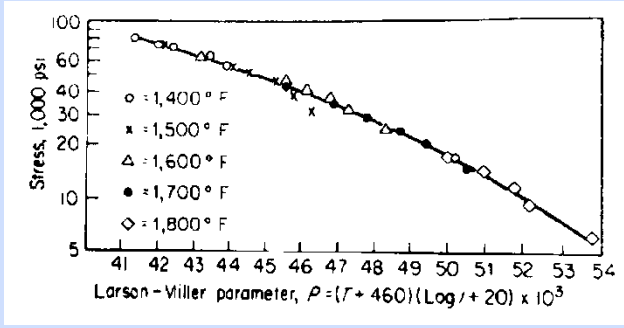


Study degradation

Determine the degradation mechanisms based on material property data and post-mortem specimen analysis

Generate prediction laws

Use material property data and environment data to generate aging prediction laws



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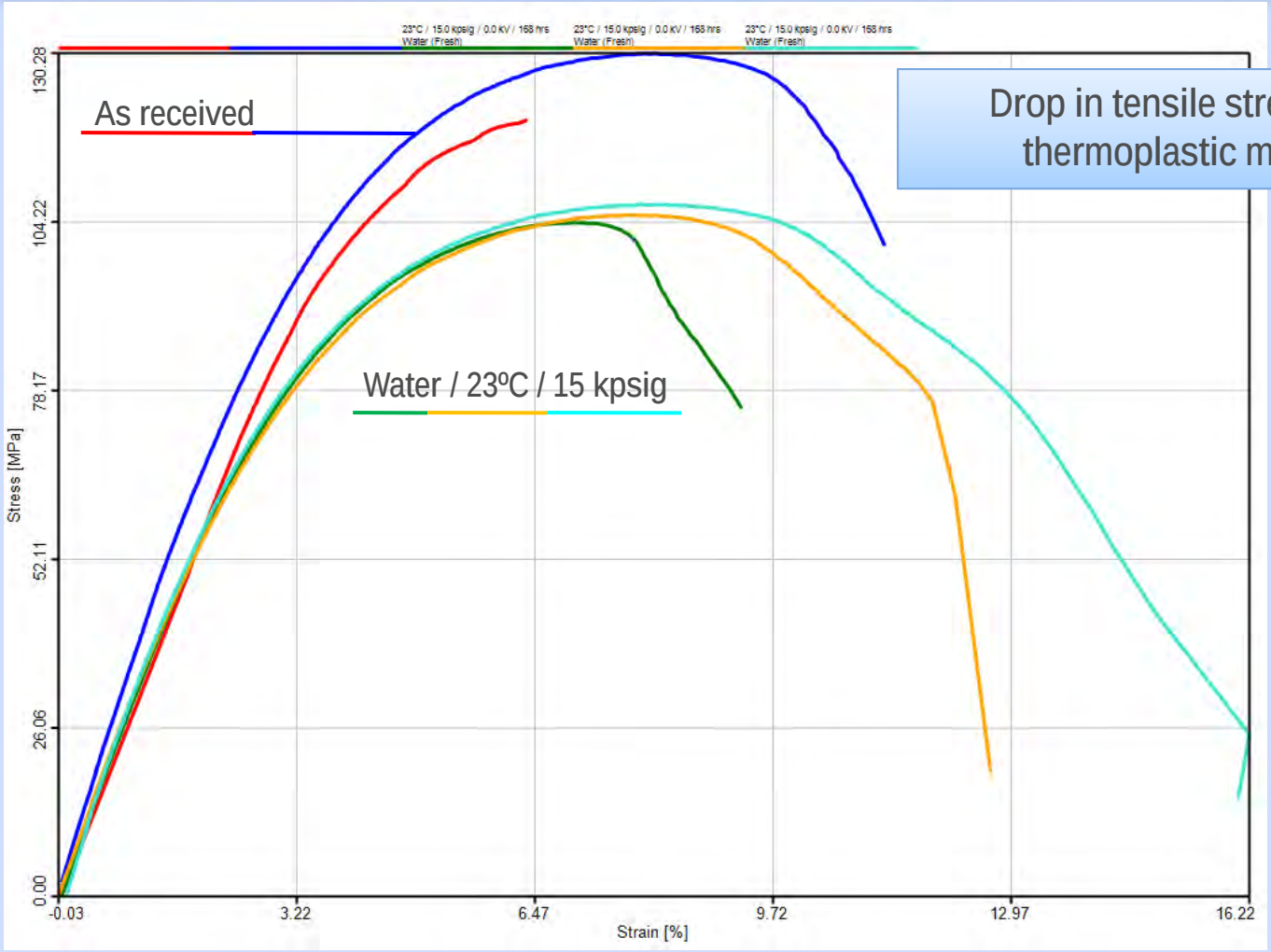
Effects of Aging



Drop in tensile strength on thermoplastic material

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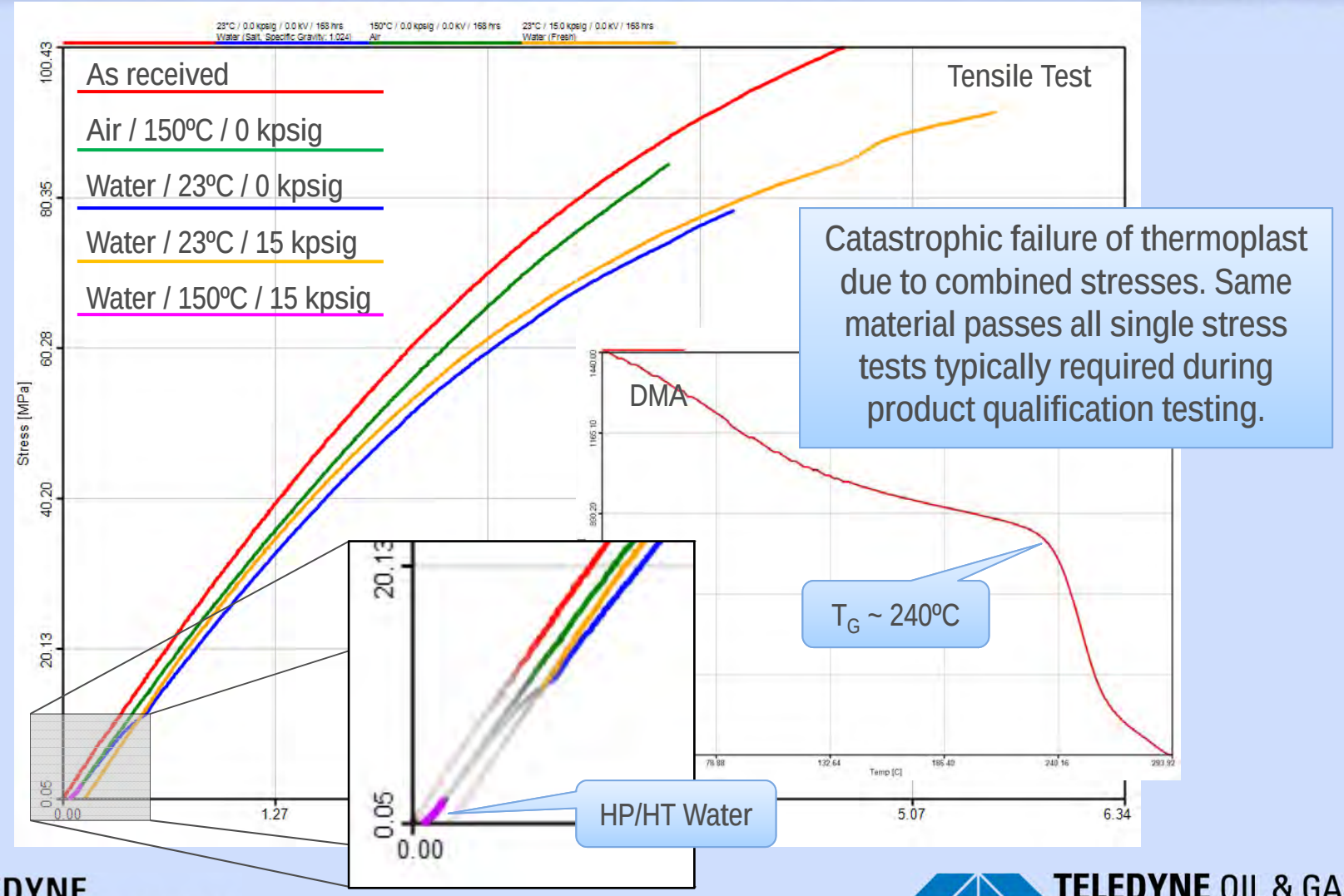
Effect of Combined Stress



Catastrophic failure of thermoplast due to combined stresses. Same material passes all single stress tests typically required during product qualification testing.

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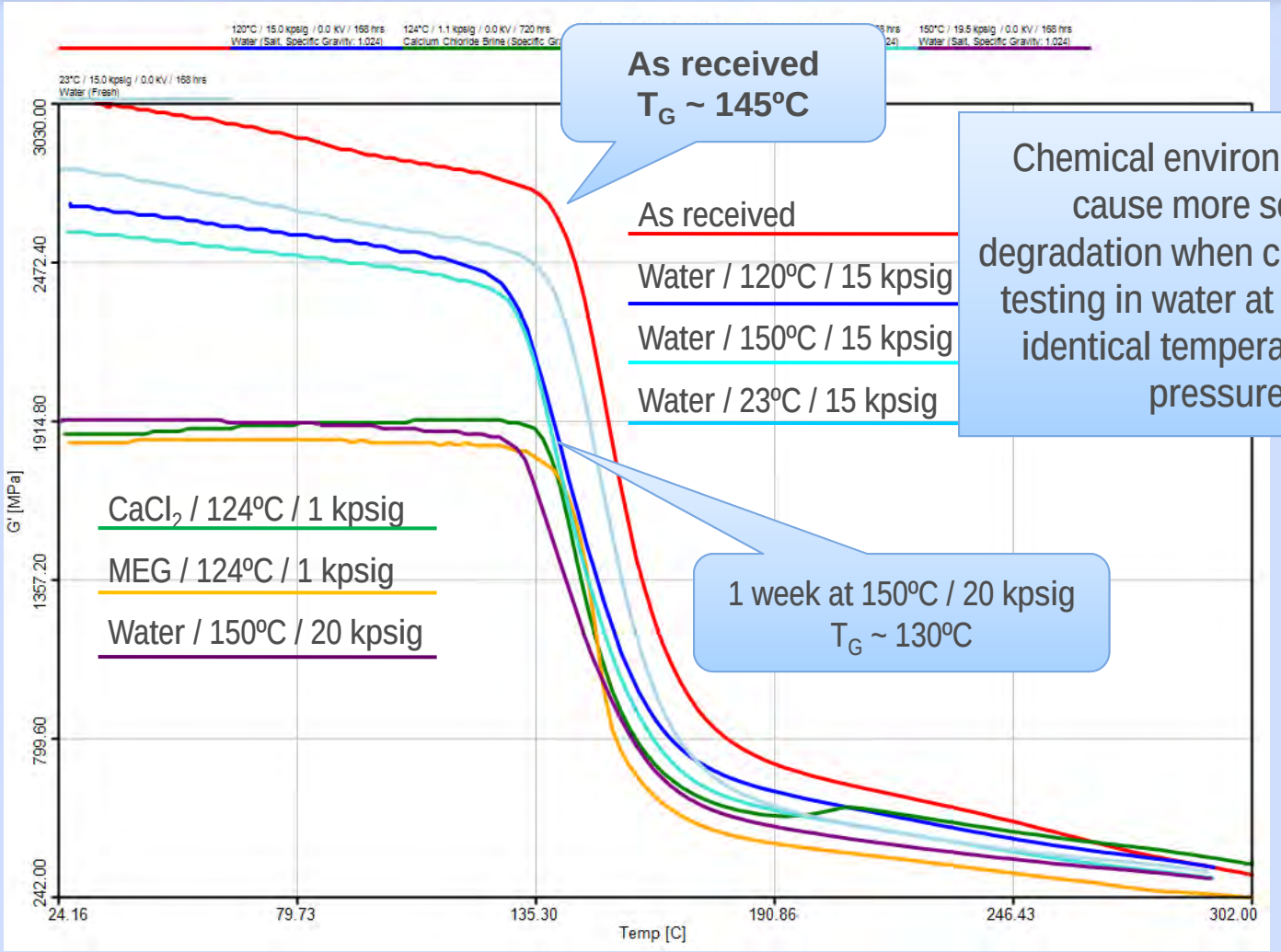
Effect of Combined Stress



Chemical environment can cause more severe degradation when compared to testing in water at otherwise identical temperature and pressure

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Post-Exposure Analysis

Electrical Properties

- DC Volume Resistivity (ASTM D257)
- AC Permittivity and Dissipation Factor (ASTM D150): 50 Hz – 2 GHz
- Dielectric Strength (ASTM D149): 60 Hz

Physical Properties (25°C – 300°C)

- Specific Heat (c_p)
- Coefficient of Thermal Expansion
- Water Absorption
- Polymer configuration changes (FTIR)
- Glass Transition Temperature (T_g)
- Thermal Conductivity
- Density
- Swelling
- Rapid Gas Decompression

Mechanical Properties

- Young's modulus, Tensile Strength, Yield Strength
- Dynamic shear modulus (25°C – 300°C)
- Hardness, Toughness

- **All properties are measured in-house on dedicated equipment**
- **Full control over all process parameters and specimen history**
- **Reduce turn-around time and minimize recovery effects**

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Deep-Sea Environment Simulation

Custom Pressure Vessel

- **2 Large salt water vessels**
  - Pressure to 40 kpsi (2750bar)
  - Temperature 0C to 250C
  - Salt water compatible
- **5 Small vessels for exposure to other environments**
  - Pressure up to 5 ksi (345 bar)
  - Temperature up to 300C
  - Process and Pump fluids
    Corrosive systems
    Hydraulic fluids
  - Rapid gas decompression
- **Sour gas aging and RGD facility in 2012**

Test Environments

- **Salt water**
- **Downhole completion fluids**
- **Hydrate formation inhibitors**

Material Groups

- **Thermoplastics**
- **Ceramics**
- **Elastomers**
- **Silicones**
- **Rubbers**
- **Epoxies**

Current Status

>100 materials and >5000 specimens

New and established materials from commercial vendors

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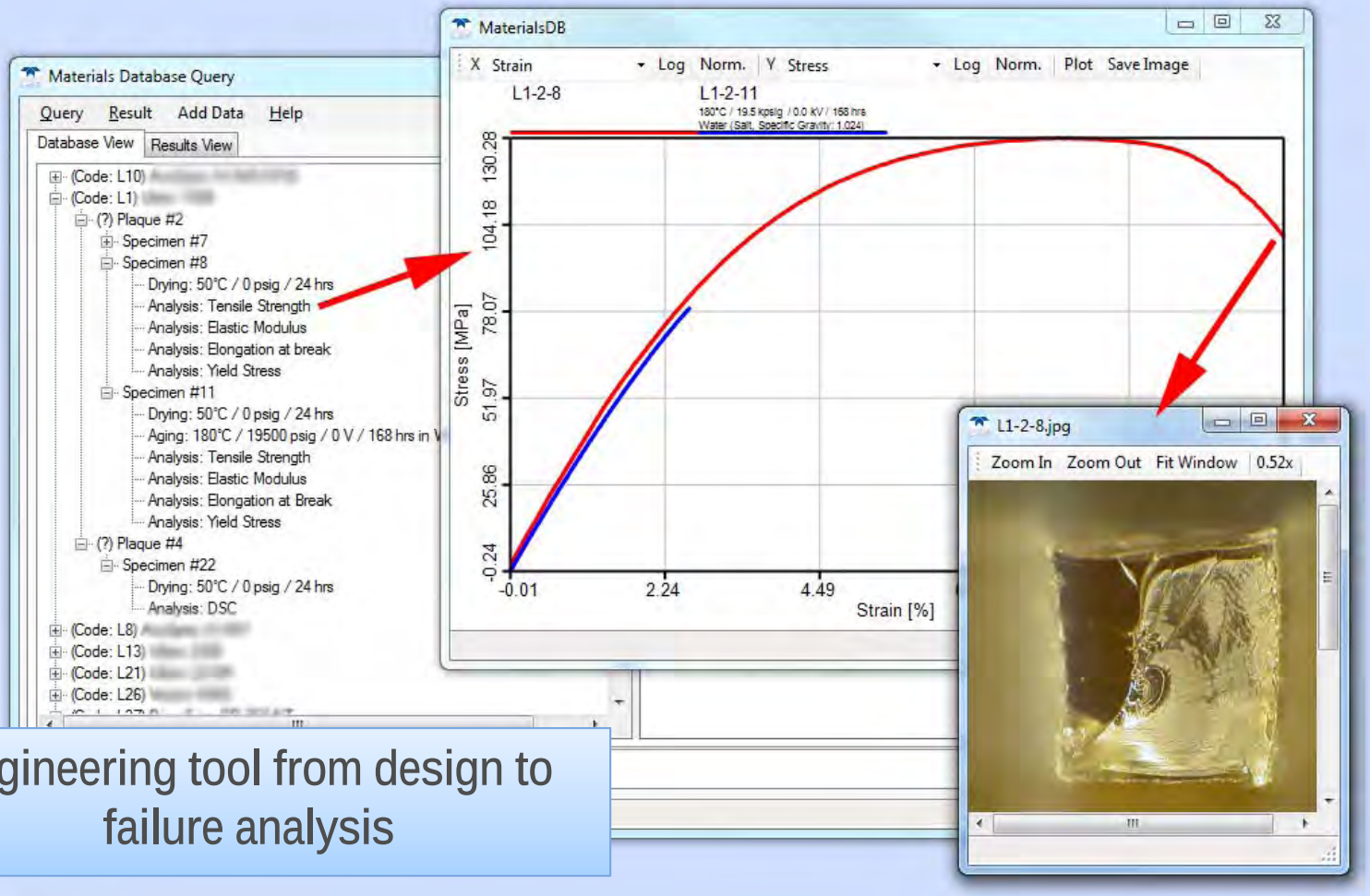
Data Retrieval as Engineering Tool



Engineering tool from design to failure analysis

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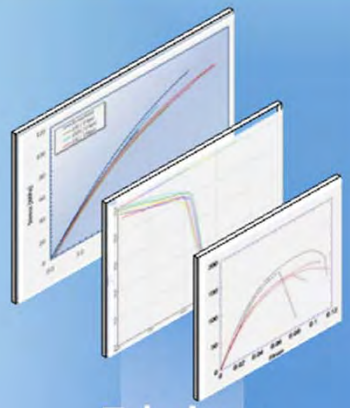
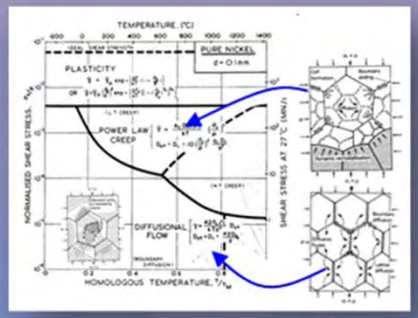
Materials Selection and Reliability

Fully Searchable Proprietary Database

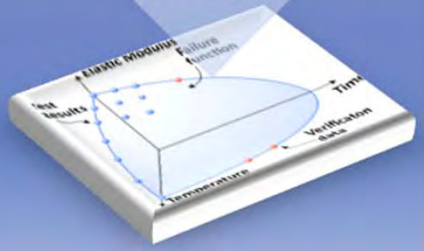


Teledyne Database

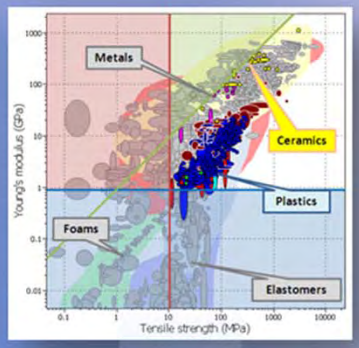
Identify Degradation Mechanisms



Reliability Analysis



Materials Selection to End-of-Life Properties



New Products

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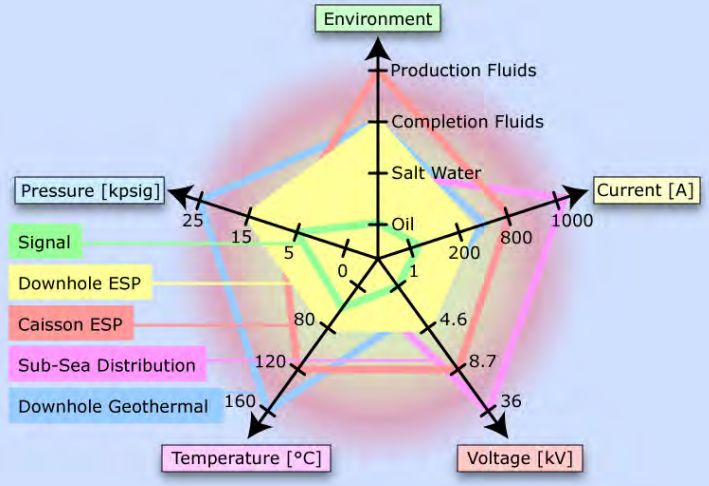
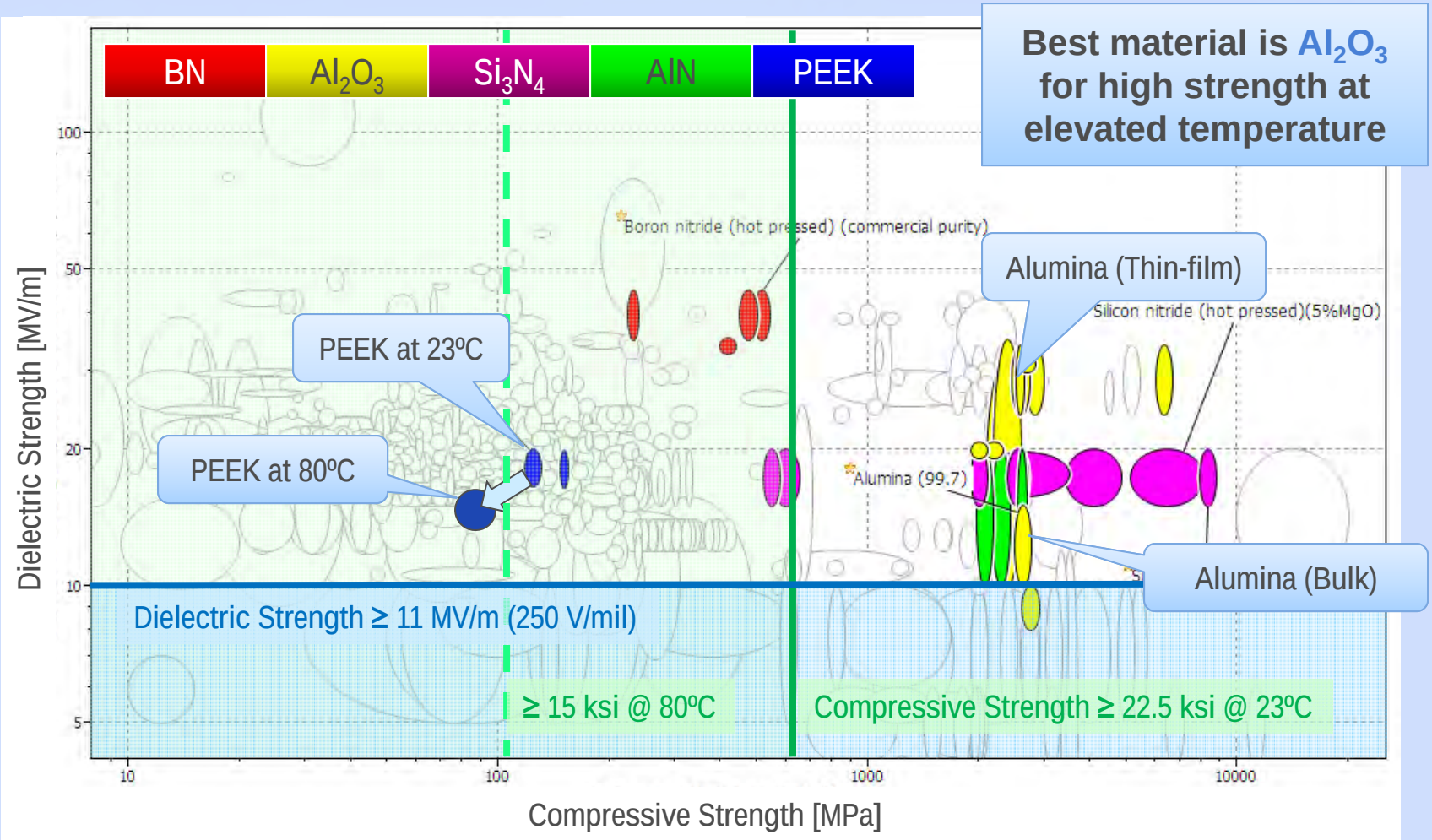
Case Study – Downhole ESP

- **Key performance req's:**
  - Completion fluid
  - 4.6 kV U_0/ 200 A
  - 80°C / 15 kpsig
- **High mechanical strength required at elevated temperatures**
- **Material that is compatible with completion fluid and any additives**



Dielectric Strength vs. Compressive Strength



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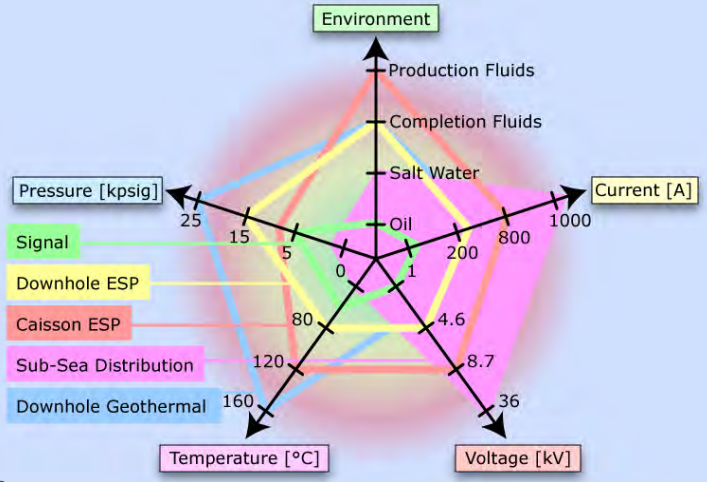
Case Study – Distribution

- **Key performance req's**
  - Salt water
  - 36 kV / 1000 A
  - 5°C / 2 kpsig
- **Material with a very high dielectric strength and electrical resistance is required**
- **Very large component**



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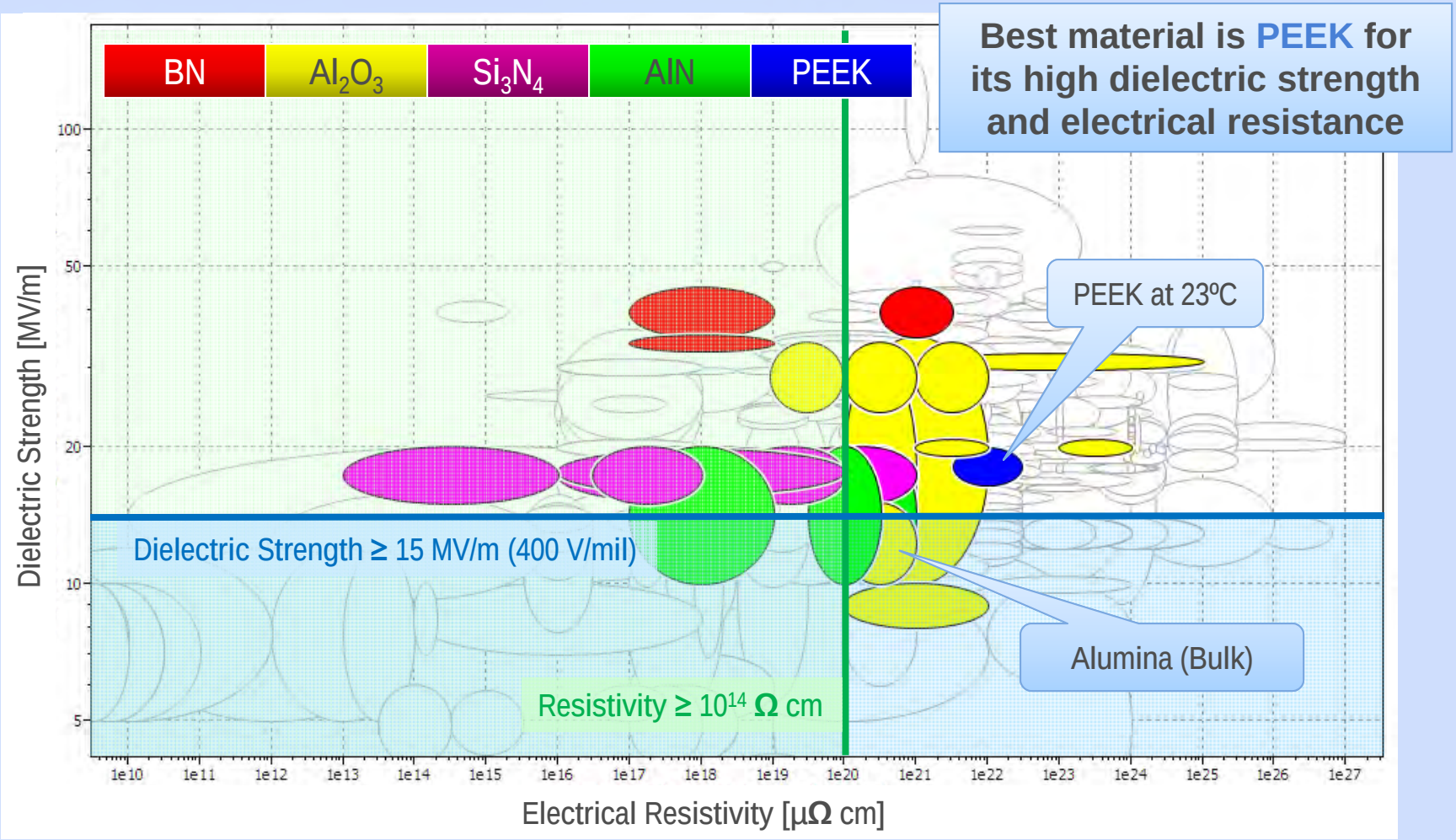
Dielectric Strength vs. Electrical Resistivity



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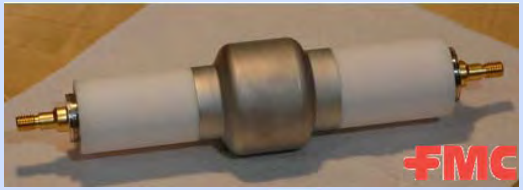
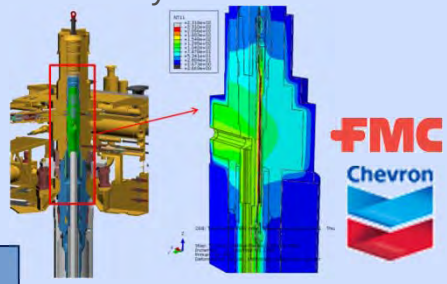
History of Successful Partnerships

New product development:
High Temperature, High Pressure Ceramic Pin
-materials selection
-fabrication process recommendations
-vendor/ customer interface



PETROBRAS

New product development:
High Temperature, High Pressure Ceramic Wet-mate
-materials selection
-fabrication process recommendations
-numerical analysis

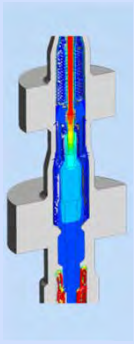


2009 | 2010 | 2011

Strategic Reinvestment Project: Materials Reliability for Deepsea Use

New product development:
High Temperature, High Pressure Ceramic Pin

TOTAL
AkerSolutions



PETROBRAS
CAMERON

New product development:
High Temperature, High Pressure Ceramic Wet-mate

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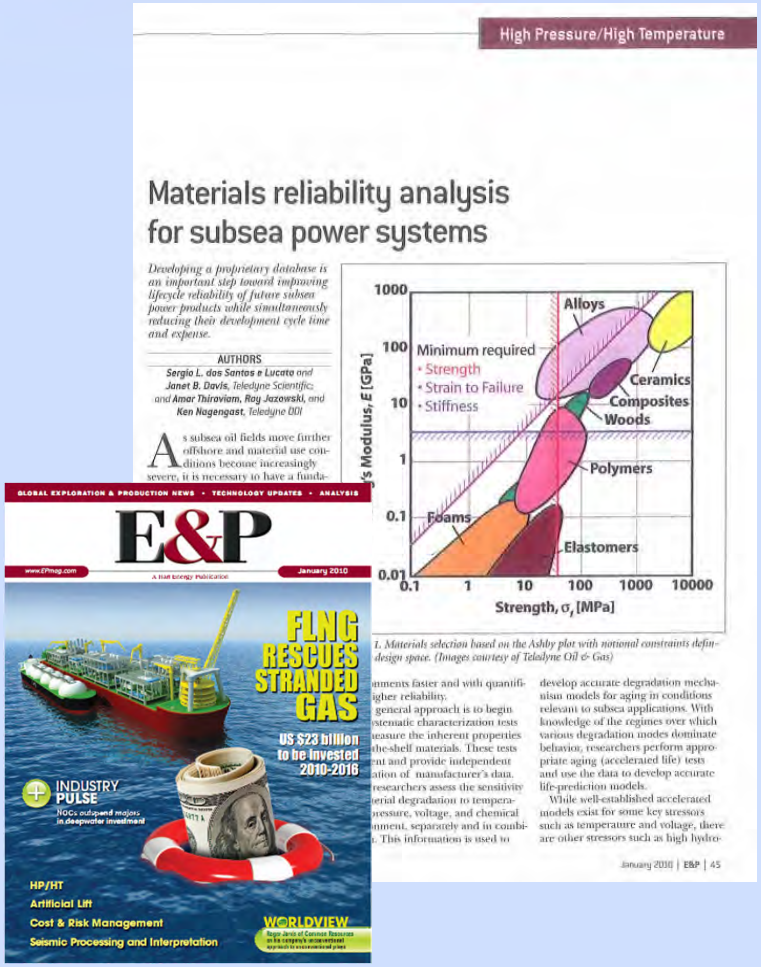
Summary

- The proprietary material properties database by Teledyne Oil & Gas incorporates **degradation mechanism identification** for accelerated aging testing and analysis.
- The resulting materials selection and life-prediction tools **reduces the product risk** of future subsea power products…
- … and simultaneously **reduces their development time** and expense.

Providing unique benefit to the end customer.



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