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U.S. DEPARTMENT OF ENERGY

Next Steps in Magnet R&D

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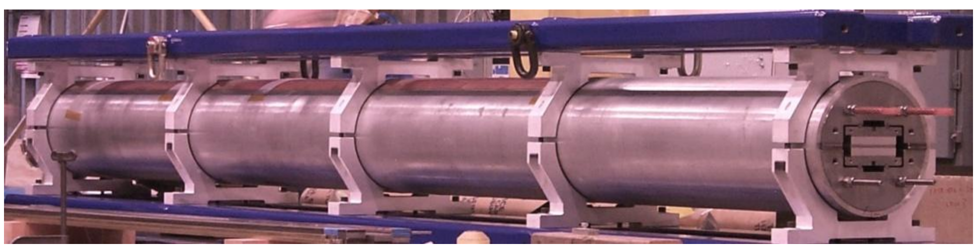
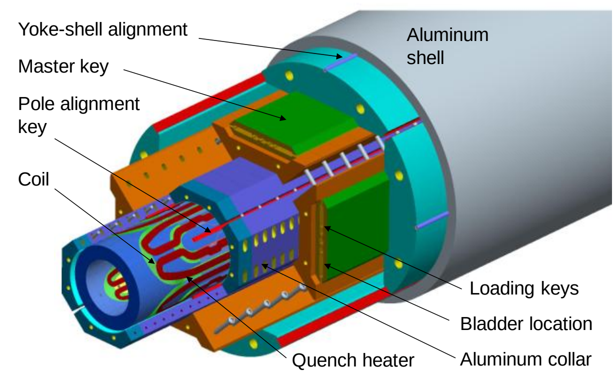
Current Status

- **Phase 1 of LARP magnet program close to completion**
  - **TQ – technology development and reproducibility**
    - ***surpassed LARP target gradient***
  - **LQ –handling, fab, protection of long magnets (~ 4m)**
    - ***achieved 220 T/m***

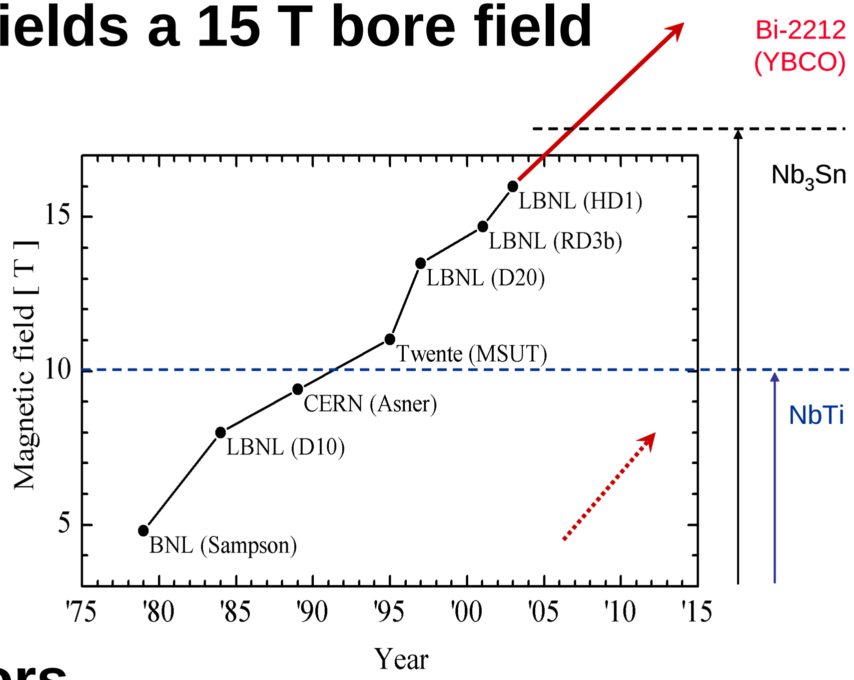




Excellent progress so far . . .

Next Phase – Two separate regimes

- **Regime 1**
  - **Up to 17 T**
    - **Nb_3Sn – optimistically yields a 15 T bore field**



- **Regime 2**
  - **Above 17 T**
    - **Introduce HTS conductors**
    - **A quantum leap in technology**

Technological Readiness

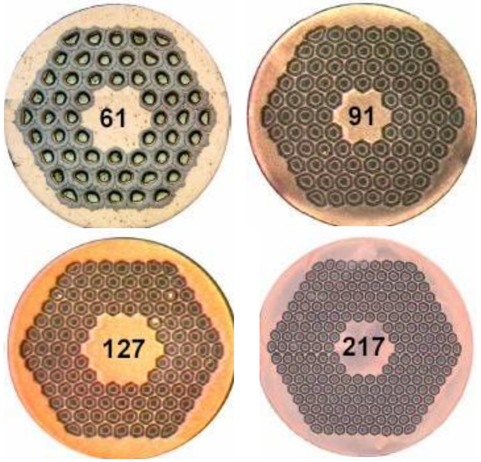
- **Ready to go or minor development still required**
- **Not yet demonstrated**
- **Need completely new idea/technique**
- **Major risk**

Regime 1 – maximizing Nb_3Sn

- **Conductor**
  - J_c
    - Nearly fully optimized
      - 3,400 A/mm^2 has been achieved. Practical limit is 4,000 A/mm^2
    - Some non-Cu area fraction is still not used for current transport (the Sn source area), but optimizing this would require a presently not available/known conductor fabrication method
  - Increase density of pinning sites
    - A factor 10 can increase the critical current around 12 T by a factor of 3.5 to 4, as demonstrated theoretically
    - Don't know how to do this in wires
  - D_{eff}
    - Still important, but more so for medium field magnets (<10 T)

Regime 1 – maximizing Nb_3Sn

- **Conductor – cont'd**
  - **Strain dependence**
    - **Poorly understood – need continued R&D**
    - **Not a show-stopper**



- **Bottom-line**
  - **Nearly ready to go**

Should we spend much more effort to raise J_c?

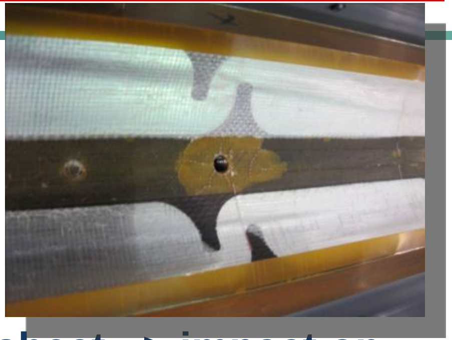
Regime 1 – maximizing Nb_3Sn

- **Preparing for high radiation environment**
  - Current filler matrix contains Boron
    - Need to transition to ceramic
  - CTD-101 not rad hard
    - Outgassing – catastrophic expansion of matrix
  - Cyanate Ester (or blend)
    - Need to understand required properties
    - Start with ITER work
  - Polyimide

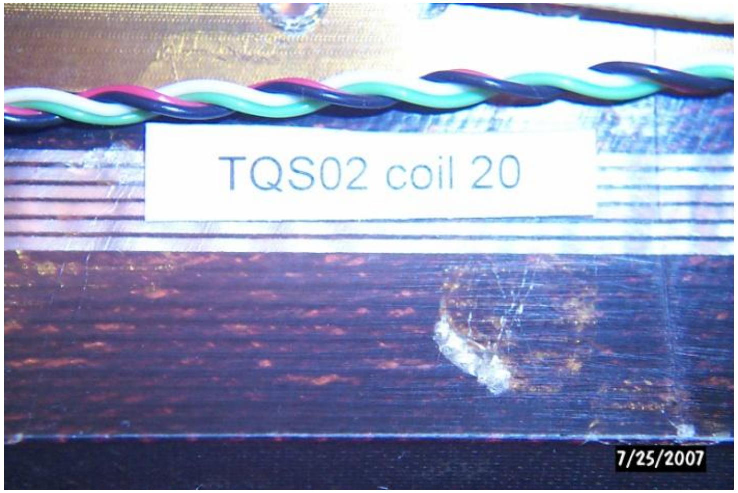
Regime 1 – maximizing Nb_3Sn

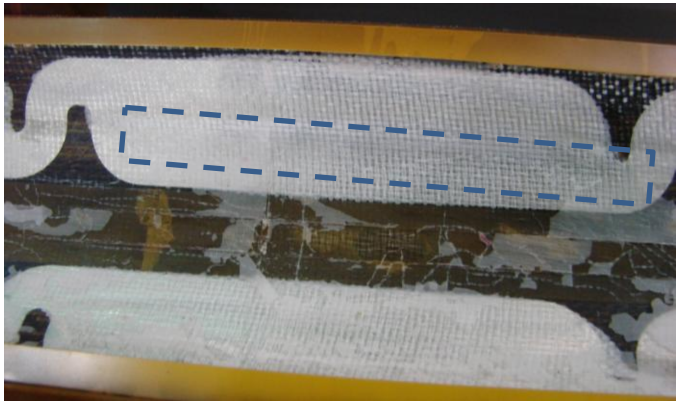
- **Quench Protection**
  - At 4 m, 14 T peak field, LQ is already a limit of stored energy. Now we want to go to 10 m and 20 T!
  - Heaters now at 400V/2m. May not want to go higher. What happens if we go to 6, 10, . . .?
  - Need more detailed quench calculations/tests
    - Include quench back
  - Mechanical issues
    - Still see some heater deformation @ 4.2K. Cycling tests are OK. Thermal cycles seem to be a problem.

Heater Delamination



- **Delamination on coil Inner Diameter**
- **Different from "TQ-style" bubbles**
  - **larger => only underneath the large sections of the heaters**
  - **No conductor exposed**
  - **Not clear if bubble underneath stainless steel or only glass sheet => impact on heater performance ?**
- **Possible causes:**
  - **Superfluid helium + quench (only 2 quenches) <=> TQ**
  - **Heat from heaters on ID <=> LQ**





Coil 6 (showing epoxy "peeling" related to double impregnation, already observed before test)

Regime 1 – maximizing Nb_3Sn

- **Structure**
  - **Field quality – know how to do this**
  - **Dynamic range? Assuming higher energy injection**
  - **2-in-1 configuration**
    - **Need to see if this is a viable option for tin magnets**

Regime 2 – 17 T and above

- **Conductor**
  - **Bi-2212**
    - J_e is presently in (almost) leak free wires around 200-250 A/mm^2 at 4.2 K, ~12 T, a factor of 3 less than NbTi and Nb_3Sn
    - A factor 3-4 increase in 2212 J_e is needed to become competitive with Nb_3Sn. Without increase, 2212 is a dead end
    - **Strain dependence**
      - The reduction of Jc with strain is irreversible in 2212
      - the intrinsic strain dependence is possibly reversible, brittle web of interconnected filaments needs to be supported in order to reduce stress concentrations
      - Potential show-stopper
    - **Other technical issues:**
      - leakage, materials compatibility, the reaction of larger coils with sufficient T and O_2 homogeneity, etc. need more R&D

Regime 2 – 17 T and above

- **Conductor (con't)**
  - **YBCO**
    - Very high current density but only 1% of the cross-section is YBCO, => J_e ~ 250 A/mm^2 comparable with 2212 and available tape insulation methods reduce this by another factor of two
    - Expensive and only available in tape form
    - Lack of filament structure
      - Can we learn how to use this?
  - **Bi-2223**
    - **J_e's comparable to 2212 and YBCO**
      - Still a tape but has filament structure
      - Perhaps it deserves a look
  - **Development of HTS conductors in industry is orthogonal to needs of HEP. How do we encourage/fund development?**

Regime 2 – 17 T and above

- **High Radiation environment**
  - Is HTS less or more rad hard than Nb_3Sn?
  - Same issues as for Regime 1
- **Quench Protection**
  - Stored energy goes even higher
  - Hybrid designs - Can we operate in series (and protect) or do we need separate power supplies?
- **Structure**
  - Integration of coils with different materials (maintain small tolerance)
    - Completely different processing for each conductor type
  - Bring together in low stress configuration (especially 2212)
  - Size – accept large stray field? Active shielding?

Summary

- Accelerator magnets with peak fields less than 17 T are challenging but clearly feasible
  - It will require a coordinated community development program
- Above 17 T requires significant conductor development and engineering
  - Much R&D to do

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