MICE CM30

Magnetic Shielding Update

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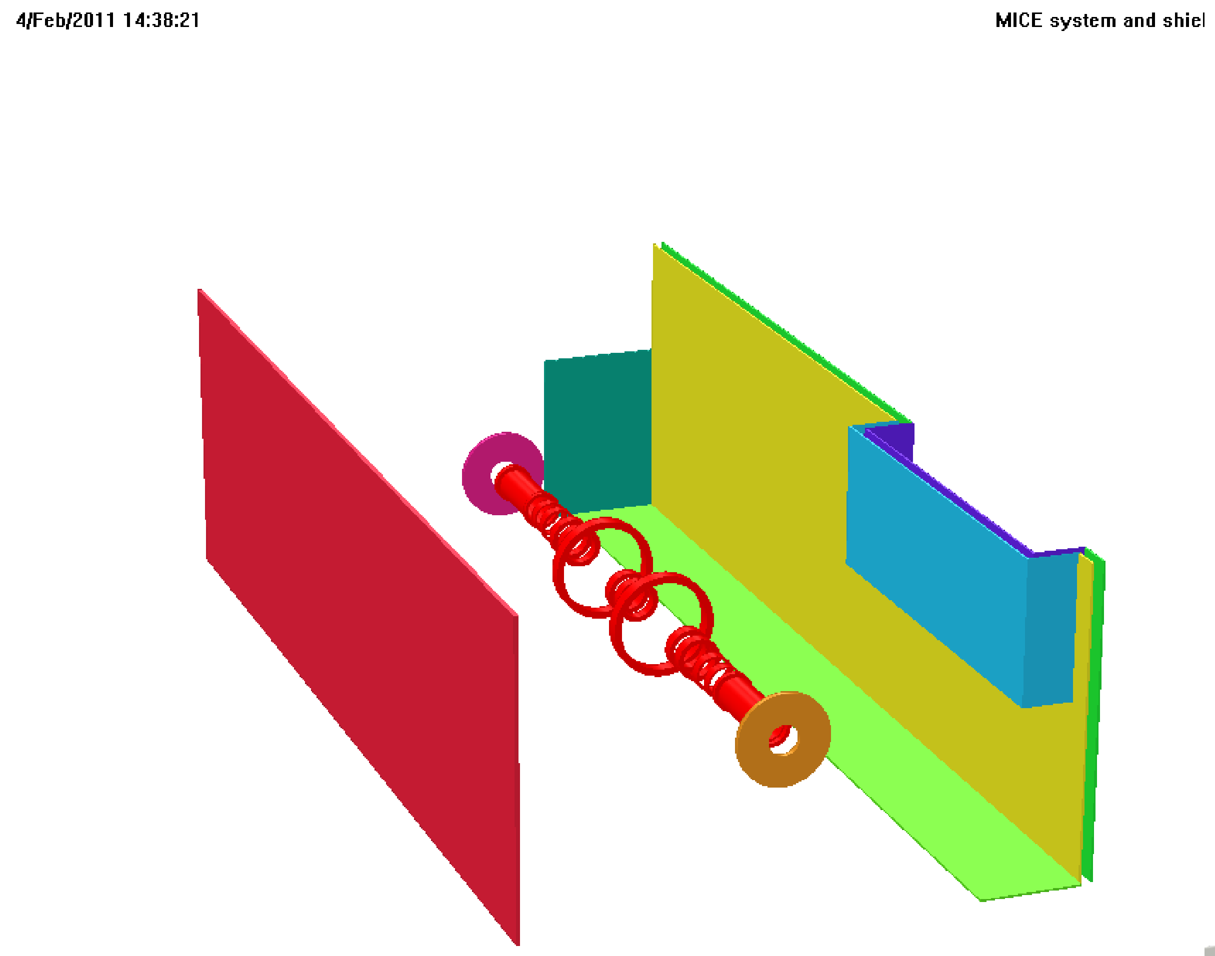
MICE Magnetic Shielding Walls
Reason for their Existence

- The MICE Magnetic Shielding walls were designed to limit the field at the periphery of the MICE Hall (with the exception of the roof) to 5 Gauss (0.5mT)
  - This is a self-imposed limit by RAL & CERN by “Best Practise”, due to the possibility that members of the public with Pace-Makers might be present in the ISIS & MICE Control Rooms
  - NB: This is not a limit imposed by legislation – which requires warning signs wherever fields in excess of 5 Gauss might be present
  - The problem with Pace-Makers is in fact limited to older units, which are switched between normal and data-downloading modes by means of a magnet. The data-downloading mode causes the battery to run down within 2 weeks.
  - ISIS have also imposed a notional limit of 5 Gauss at the wall of the Injector Hall, to avoid fringe field effects on the ISIS LINAC
    - NB: This limit has never been formally justified by ISIS

Phase VI, Solenoid mode, 240MeV/c
VF Opera Magnetic Shielding Wall Model



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Phase VI, Solenoid mode, 240MeV/c
Problem with conductor definition file

- Additional analysis performed to check the effect of the magnetic shielding wall on beam optics, and subsequently published as a MICE Note, predicted that the peak fields experienced external to the MICE Hall and at the ISIS Control Room wall would be 19.0 & 17.5 Gauss resp.
    - This was significantly higher than the magnetic shielding wall design aim of 5 Gauss maximum for each of these areas, but not noticed at the time.
    - The difference was eventually traced to an error that crept into the conductor definition file for Solenoid mode, which had been altered back in August 2007 to reflect the change from 200 to 240Mev/c, plus conductor geometry changes.
    - All Solenoid mode models since August 2007 were thus in error
    - Representative models were subsequently rerun with corrected data, to compare results, and thus understand the effect of the error on the predicted performance of the magnetic shielding wall
    - Initial conclusions were that the error was only significant for Step VI in Solenoid mode
    - Subsequently, another error was discovered in the data used for Step V, which strongly affects the field produced by the single Coupling Coil in this mode. It was thus important to re-analyse the results for Step V in Solenoid & Flip modes
        - NB: The field of the Coupling Coil in the centre is not cancelled in Step V Flip, unlike other modes

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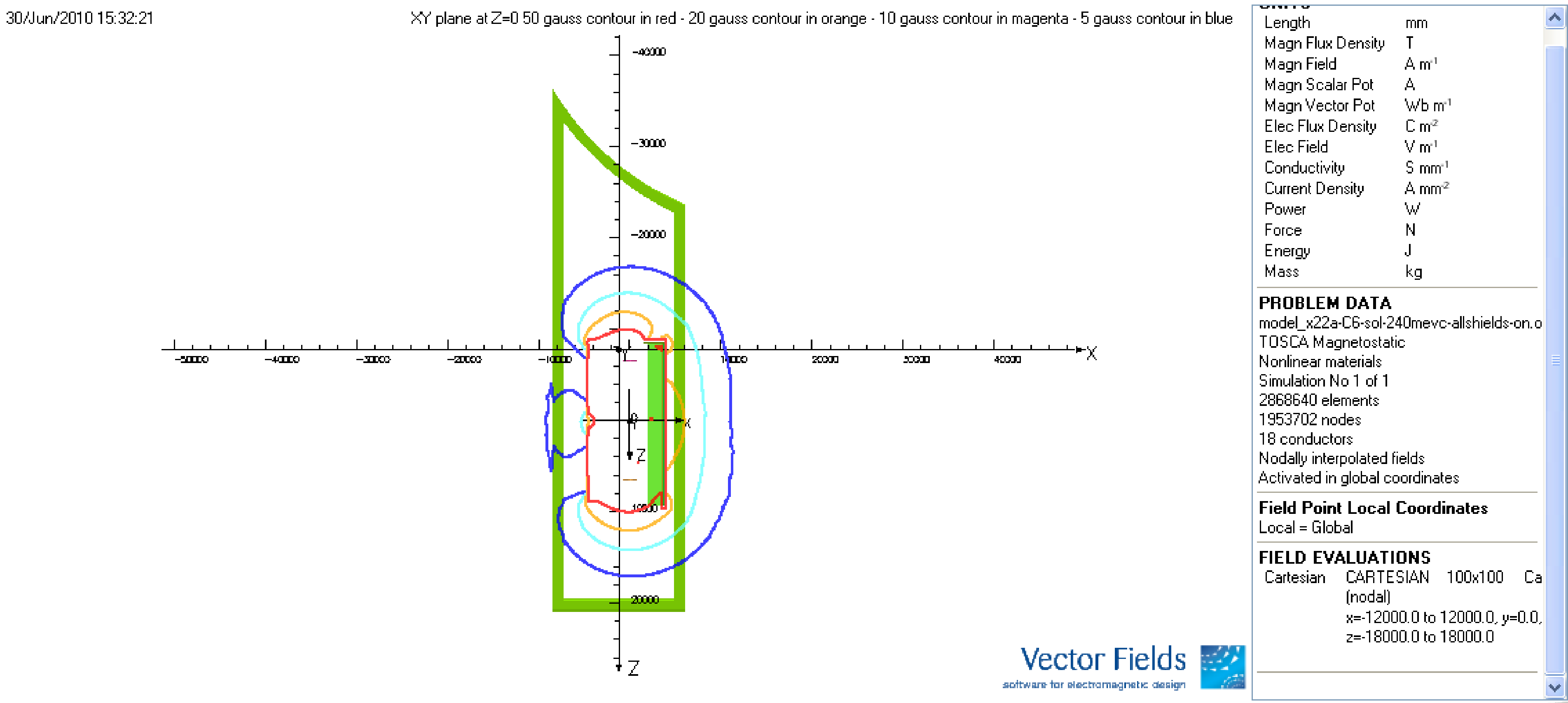
Phase VI, Solenoid mode, 240MeV/c
Corrected model - All shields on



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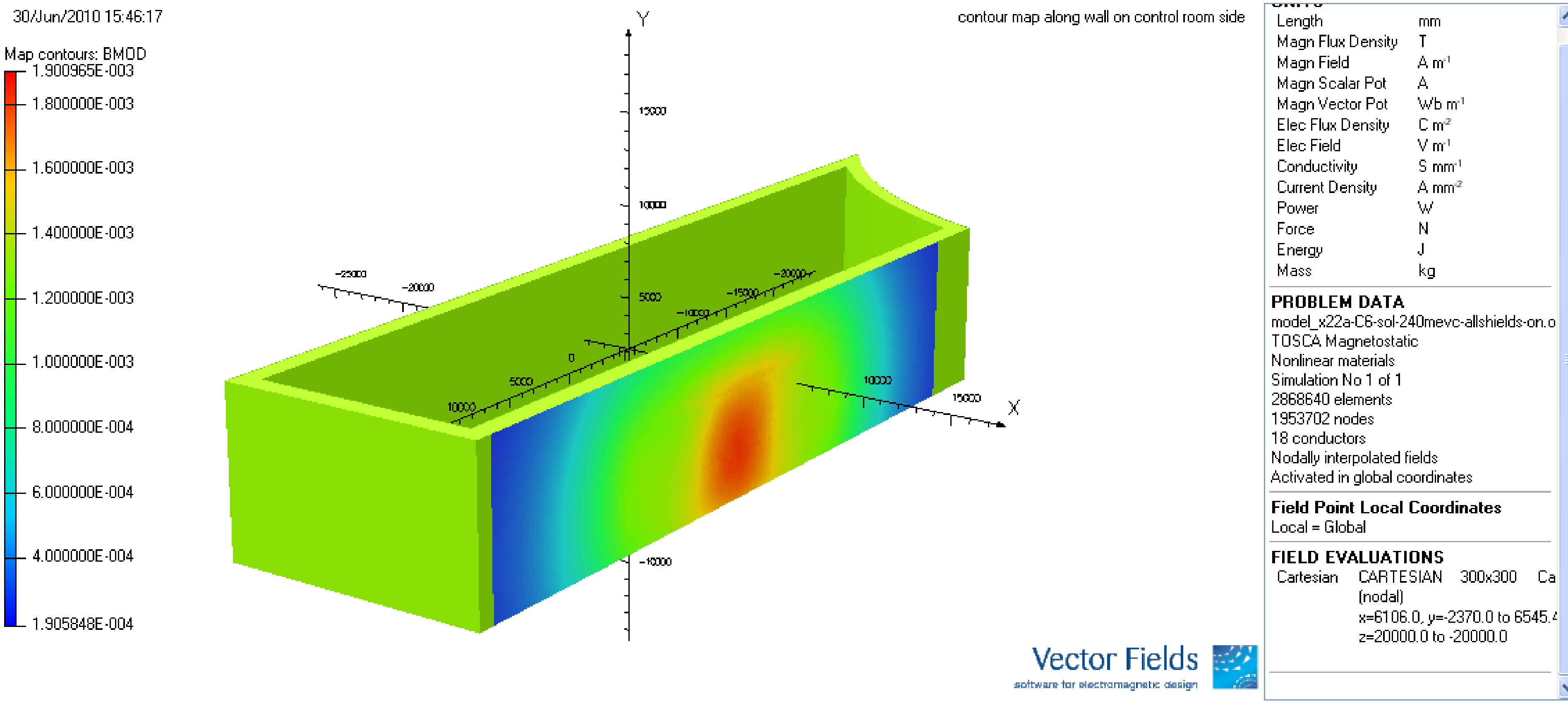
Phase VI, Solenoid mode, 240MeV/c Corrected model - All shields on



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Phase VI, Solenoid mode, 240MeV/c
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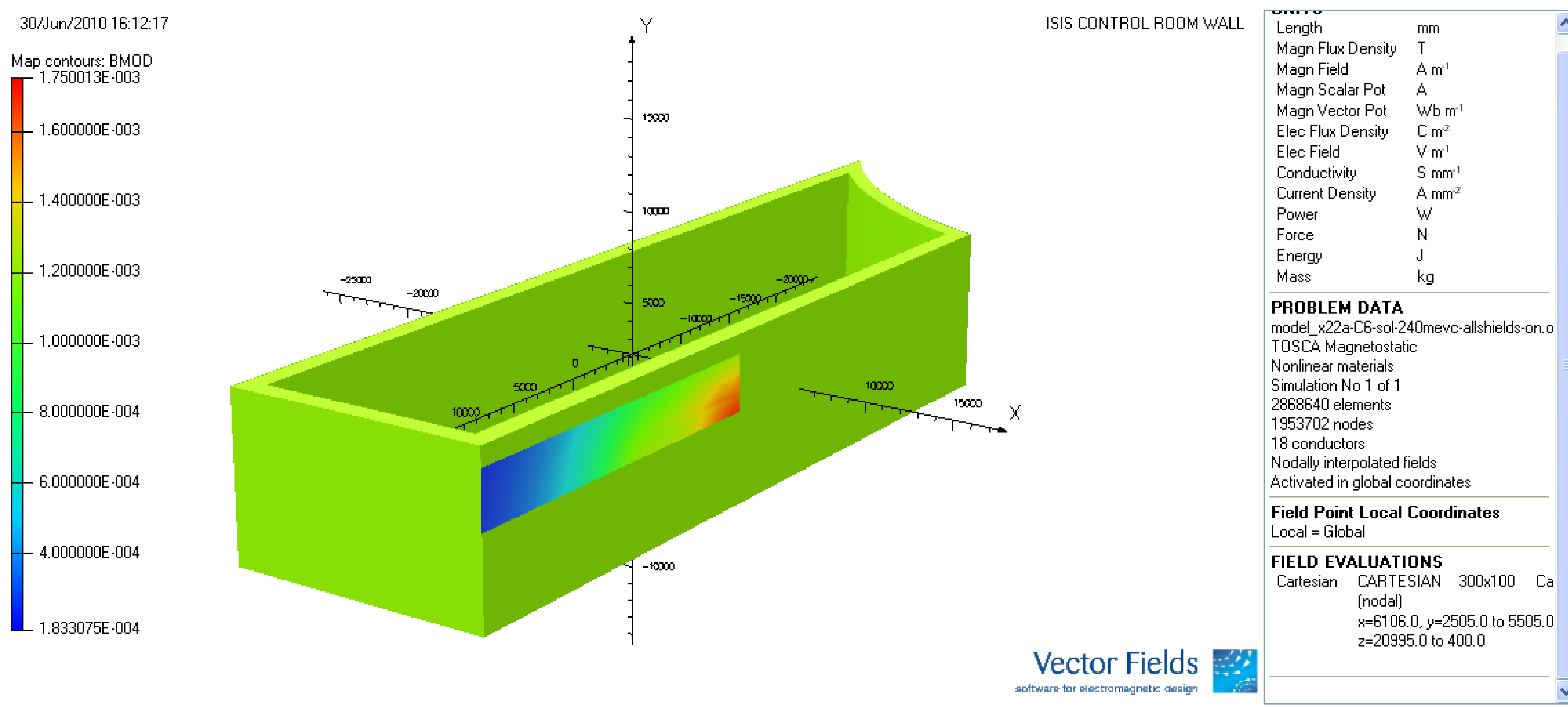

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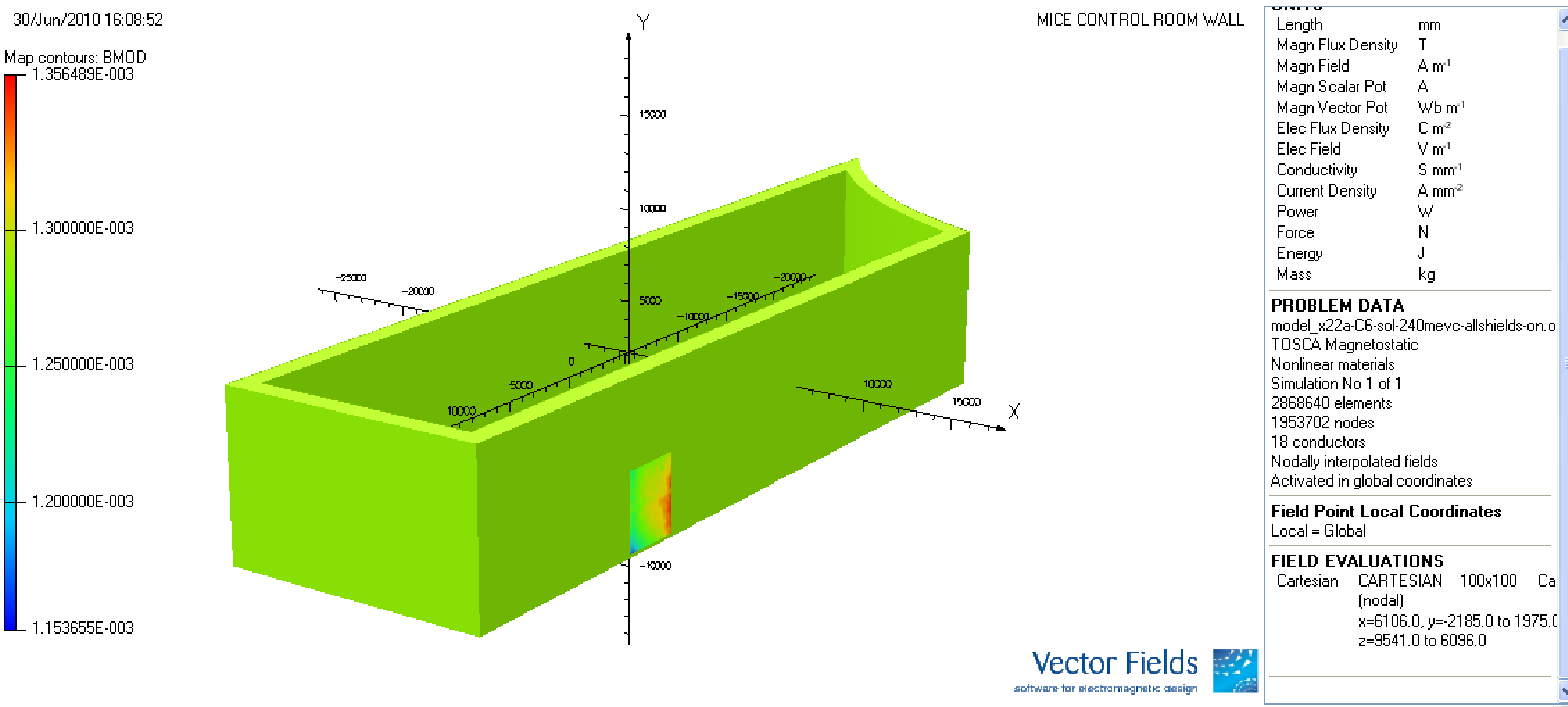
Phase VI, Solenoid mode, 240MeV/c Corrected model - All shields on



Report from Vector Fields consultant

- **Accuracy of the Existing Model**
  - The Opera software uses methods that allow the fields from coils and iron to be separately calculated (reduced potentials)
  - The coil fields are calculated to very high accuracy by integration
  - The iron fields are calculated using a finite element method
    - However in regions where the coil and iron fields cancel, this approach tends to amplify the errors in the total field.
      - This can be avoided by specifying whether a total field FE solution is required in particular regions of space.
    - The magnetic shielding in the models reduced the field in the ISIS & MICE Control Rooms from 16 mT to 1.8mT, implying 90% cancellation of the coils' fields
      - It is thus appropriate to use total field solutions in shielded areas.
      - Opera reported an expected error of 1% in its FE solution; the cancellation would increase the error in the total field to approximately 10%.
      - The models were thus modified to use the total field solutions in all regions exterior to the cylinder containing the superconducting coils.
        - »The calculated fields in the control room changed by approximately 8%, in good agreement with the program's expected error.

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Report from Vector Fields consultant

- The accuracy of Opera's finite element solution is related to the element size and the solution exhibits quadratic convergence as the finite element's linear dimensions are reduced.
    - The element size was therefore reduced in the MICE model, to establish confidence in the programs expected error calculation.
        - The results obtained using Opera agreed with the programs error predictions and behaved consistently when the models were refined.
        - The program predicts maximum fields of 1.7mT in the ISIS and 1.5mT in the MICE control rooms with the existing shielding configuration, when the shields are manufactured from annealed US1010 steel.

Report from Vector Fields consultant

- **Steel characteristics**
  - Annealed US1010 steel has been frequently used to manufacture magnetic shielding for high field NMR magnets.
  - The magnetic characteristics of the steel have been measured for many samples and the performance of the shields has been reliable.
  - The magnetic performance of US1010 that has not been annealed is very variable.
    - The initial model for the MICE shielding has been recalculated using average properties for un-annealed US1010 steel and the fields in the ISIS and MICE control rooms increased to 2.5mT.
  - Annealed US1010 properties are used for all results in the interim report, except where other steels are used to look at sensitivity.

Report from Vector Fields consultant

- **Update of Results following BH Measurements at NPL**
  - The existing shield configuration was recalculated using the measured BH characteristics of the steel. The NPL measurements used a number of samples from the shield, the shield performance was recalculated using the poorest magnetic performance that was measured.
  - The table compares the original results using SLACs measured US1010 annealed steel properties and the recalculated results using the worst properties measured by NPL.

Model 0	Total Steel Mass (Tonnes)		ISIS control room Bpeak (mT)	MICE control room Bpeak (mT)
SLAC US1010	113.8		1.7	1.5
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Report from Vector Fields consultant

- **Options for Improving MICE magnetic Shielding**
  - The initial configuration of shields shows some saturation of the steel in the Control room shielding walls and floor plate.
    - A calculation using a fixed high permeability for the steel provides an easy way to check the maximum efficiency of a shielding configuration.
    - This calculation showed that if the shielding walls were increased in thickness so that the flux density in the steel was below 1T, the maximum field in the ISIS control room would be 0.47mT and in the MICE control room 0.46T.
    - The constant permeability result also gives an immediate indication of the positions where increased shield thickness is required.
  - NB: Increasing the shielding plate thickness is an option, but the safety margin is small.

Report from Vector Fields consultant

- **Increased shielding plate thickness and/or additional shielding plates**
  - These results indicate the scale of the increases in thickness needed to improve the shielding performance.
  - Additional shielding plates were added close to the coils, as shown in the figure
  - The maximum fields in the ISIS and MICE control rooms for various shielding configurations is shown in the table, together with the mass of steel compared to the existing magnetic shielding.
    - Model 0 – the existing magnetic shielding plates
    - Model 3 – increased thickness of existing shield plates
    - Model 8 – existing plates plus new close in shield plates
    - Model 10 – increased thickness of existing plus new close in shield plates

Model	Total Steel Mass (Tonnes)	Change in mass cf Model 0 (Tonnes)	ISIS control room Bpeak (mT)	MICE control room Bpeak (mT)
Model 0	113.8	0	1.7	1.5
Model 3	123.9	10.1	0.98	0.96
Model 7	139.4	25.6	1.10	0.86
Model 10	147.0	33.2	0.69	0.71

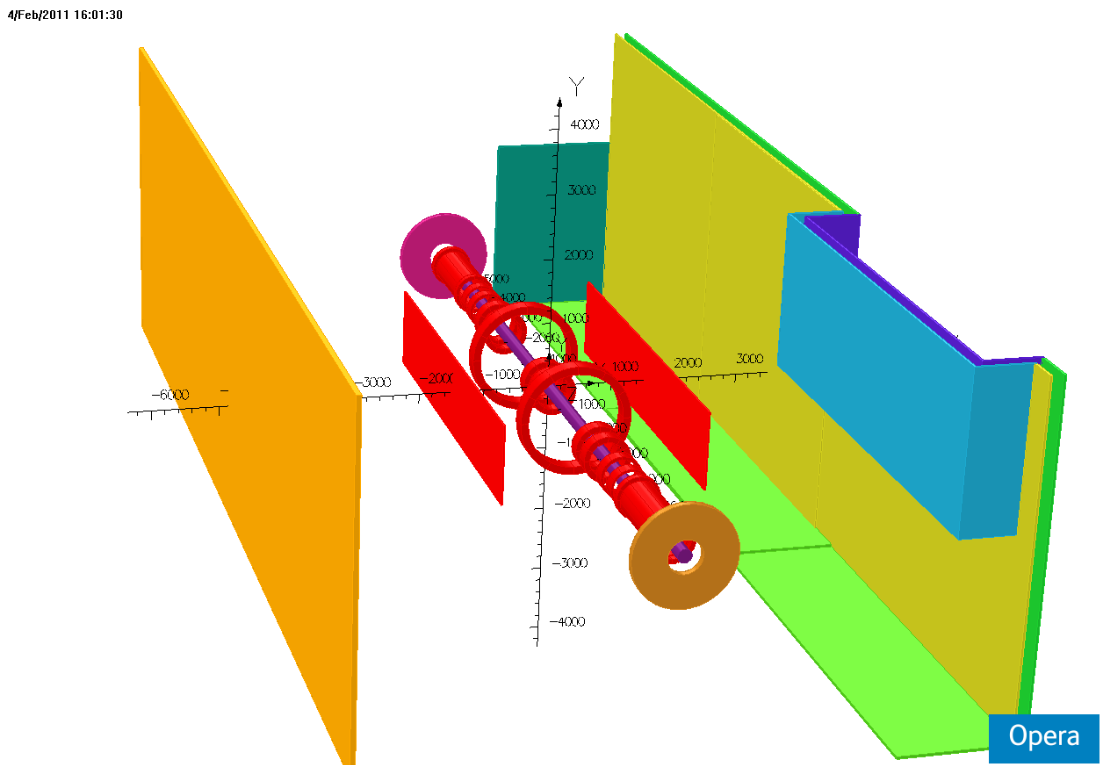
Report from Vector Fields consultant

- **Review of shield performance**
  - The results show that to achieve the same improvement in shielding, increasing the thickness of the control room floor and wall plates requires less steel than is required by the close in shields (compare Model 3 and Model 8 which have similar peak fields in the control rooms).
  - The improvement in shielding is localised by increasing the existing floor and wall plate thickness close to the control room, whereas the close in shield improves the shielding in all directions.
  - A single sided close in shield was not considered, because it creates a sideways force on the coils of 5 Tonnes.

Report from Vector Fields consultant

- **General Comments**
  - The distribution of the stray field in the control rooms was very similar for all the configurations studied, the simple approach of comparing the peak fields in the control room is therefore representative of the shielding improvement.
  - The close in shield plates have only been added at the side of the coils because it would be difficult to add plates at the top and bottom. The plates have to be positioned approximately 1.7M from the beam line and at this distance the side plates only become effective at shielding the ISIS control room if they extend 2 Metres above and below the beamline. There is a large force between the coils and the close in shields; the shields must therefore be symmetrically positioned so that the force on the coils is balanced.
  - In the simulations, the lowest peak field achieved in the ISIS control room was 0.69mT and in the MICE control room 0.71mT. The was achieved by adding an extra 33 Tonnes of steel (19 Tonnes in the new close in shields and 14 Tonnes added to the existing structure).

Report from Vector Fields consultant



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Report from Vector Fields consultant

- **Is there a Practical Solution?.**
  - With the constraints imposed by the existing configuration of the MICE hall it will be difficult to achieve less than 0.5mT in the ISIS and MICE control rooms when MICE is operated in the mode that gives the highest stray field.
  - Adding an extra 10 Tonnes of steel to the existing steel walls would reduce the fields in the control rooms to below 1mT. To reach 0.5mT will require of the order of 50 Tonnes of additional steel added to the existing steel wall and floor plates
    - Is this a practical solution?
- **Are there any other options?**
  - Fitting a shielding box around the control rooms hasn't been considered.
    - This type of shielding is not efficient, but it might be the only way of reliably reducing the field below 0.5mT.
    - However it's likely to be extremely difficult to construct this shielding.

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    - However it's likely to be extremely difficult to construct this shielding.
  - The most practical solution is to identify under which conditions the magnetic field will exceed 5 Gauss beyond the MICE Hall boundary, and seek permission to operate the MICE Cooling Channel magnets in these conditions with Controlled Access to areas such as the ISIS & MICE Control Rooms.

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