Summary of Taurus Reservoir Solutions Stakeholder Feedback and Reservoir Containment Team (RCT) Response on Technical Reports				
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RC-04Sec 4.1, p.3 “ABAQUS’s parallel solution technique makes it possible to run large-scale coupled models, such as for a full SAGD pad”	ABAQUS cannot be coupled to a full multi-phase, thermal simulator the coupled runs - it can only do single-phase fluid flow. The typical way SAGD results are coupled to ABAQUS is one-way coupling where for select time steps the pressure and temperature solution is applied as changes to the ABAQUS geomechanical model. There is no feedback of coupling parameters to the flow model (i.e. permeability or porosity changes)	Provide a better definition upfront of the coupling methods used in industry: 1. One-way sequential coupling (no coupling terms update to flow solution) 2. Explicit sequential coupling (coupling terms are updated explicitly (i.e. from the previous time step) 3. Iteratively coupled (several iterations are performed within each time step to ensure convergence between the two modules (reservoir simulator and geomechanical simulator)	Settari, A. and Walters, D.A.: “Advances in Coupled Geomechanical and Reservoir Modeling With Applications to Reservoir Compaction”, SPE Journal, Vol. 6, No. 3, Sept. 2001, pp. 334-342.	The RCT acknowledges that the suggested possible solution is an alternative way to describe coupling between geomechanical and reservoir simulators.
RC-04Sec 4.1 p.3 “their ability to simulate the response of a discrete, naturally fractured system is limited”	Geosim has two constitutive models to deal with the discontinuous behavior of a fracture in a continuum. 1.) special elements (fault elements) to deal with large scale discrete features like faults (ref. 3). Also, an equivalent continuum model (fracture sets + matrix) is available that can account for fracture networks (ref 2). Also, Geosim is used routinely to model tensile fracture propagation (Produced water re-injection PWRI, waterflood fracturing, waterfrac stimulation in tight formations. It can reproduce the classical linear elastic fracture solutions (ref. 1)	Give accurate information about the capabilities of Geosim for fracture and fault modeling	1. L. Ji, A. Settari and R.B. Sullivan : “A Novel Hydraulic Fracturing Model Fully Coupled with Geomechanics and Reservoir Simulator”, SPE Journal, Vol. 14, No. 3, Sept. 2009, pp. 423-430. SPE110845	The RCT continues to believe that the ability of geomechanical models to simulate the response of a discrete, naturally fractured system is limited.

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RC-04Sec 4.1 p.3 “However, its ability to run large-scale coupled models within a reasonable timeframe is limited”	3D explicitly coupled sector models are usually run with a MOP study. A parallel version is set for release in a year and will allow larger models to be run.	Give accurate information about Geosim capabilities	Taurus communication (owner and distributer of Geosim)	The RCT is not in a position to speculate on the possible release of new software.
RC-04Sec 4.2 p. 4 “the capability of such a model is limited when used to assess caprock shear failure for an entire SAGD well pattern because this type of model does not include actual edges, where shear failures are most likely to occur”	This comment is inaccurate. Typically all the models run by Taurus investigate both an interior well as well as an edge well or pattern with edge conditions. So the edges are simulated and do show risk of failure. It is true mostly 2D runs have been submitted, but nowadays a 3D case is also submitted to investigate 3D effects	Revise statement to more accurately reflect the understanding of where shear happens. It is at the edge of the steam chambers. In the first few years of operation this happens at the edge of a pattern, but also internally between wells. So, these symmetry models do have value to investigate shear at the base of the caprock. As things mature and the edge is only at the edge of the pattern the shear loaded zone actually smears out and is not as severe as earlier in the life of the operation.	Experience in modeling these processes. If the AER does not agree with this please invite Taurus in for a discussion of our modeling experience of SAGD processes.	The RCT acknowledges the shear failure region will change over the life of a well pattern. The RCT believes the greatest risk due to shear failure is in the later stages of the well patterns life when the maximum amount of energy is stored in the reservoir.

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RC-04Sec 4.2 p.4 "A far-field in situ stress condition should be imposed on the far-field boundary together with a reasonably designed mesh or block size."	A far field stress condition is the wrong boundary condition. The standard boundary condition for modeling of any reservoir system is uniaxial strain (no lateral displacement) or rollers. You can argue pins or rollers are valid far away from the perturbation, but typically it only makes a small difference. If a stress boundary condition is assumed that assumes constant horizontal stress is maintained the boundary is free to move – this is not correct. However, if a stress boundary condition is applied far enough from the perturbation it will also not significantly affect the solution.	Soften the verbiage. Rollers, pins and stress boundary conditions are all an approximation to the real condition. If there is material adjacent to your reservoir, that material has a low compressibility and if the reservoir tries to expand laterally only rollers and pins will correctly predict the change in horizontal stresses. A constant stress boundary condition is like a triaxial test – free lateral expansion… not reservoir conditions	This is well understood by the modeling community	The RCT continues to believe that applying a roller boundary condition to the far field boundary rather than a stress condition is acceptable as long as the boundary is set far enough from the edge of the last steam chamber.

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RC-04Sec 4.2 p.5 “a)To simulate the shear effects indicated in figure 1, the model must contain more than one steam chamber. The shearing is likely to be the greatest at later times because the greater the reservoir volume that is heated, the greater the total displacement that occurs at the edges of the SAGD zone”	This is not true. The statement assumes bending is the only mechanism to cause shearing. In fact it is coupled to pressure and temperature changes and their distribution. The longer a SAGD process runs the more smearing of the pressure and temperature front occurs. This tends to reduce the bending effect of the expansion due to pressure and temperature change. So there are early times when the bending coupled to expansion due to dP and dT can be very important and cause larger shear loading at the base of the caprock. Once the pattern becomes larger and coalescence occurs the displacement at the middle of the pattern becomes 1D and all bending goes away. The remaining shearing is at the edge, but the gradients of temperature and pressure at the edge at this late time in the operation are smaller than earlier in the life of the operation. True the vertical displacement is larger later in the life.	Fix the statement to be accurate.	This concept was covered in Suncor Mackay SIR responses to their MOP application	The RCT believes the greatest risk due to shear failure is in the later stages of the well patterns life when the maximum amount of energy is stored in the reservoir.

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RC-04Sec 4.2 p. 5 “c) The bottom boundary is a roller boundary, but there must be some reasonable thickness of the underlying strata in order to make sure that the boundary proximity is not affecting the results. The thickness of the underburden should be 4–5 times the thickness of the SAGD zone”	You could argue it should be rollers or pins, but yes it should be far enough away to not significantly impact solution. Rollers assumes the bottom surface is a slip surface (not the case). Pins assumes the bottom surface does not expand laterally (not the case, but maybe closer to the bottom being a very stiff formation and good bond to overlying material).	Correct statement to focus more of the fact that the boundary condition must be far enough away from the perturbation to not significantly affect the answer.	Taurus modeling experience	The RCT agrees that the boundary condition must be far enough away from the perturbation to not significantly affect the answer.

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RC-04Sec 4.2 p.5 “d) To maintain the far-field stress equilibrium condition, the far-field boundary should be constrained with the in situ stress condition. Any model that uses zero displacement boundary conditions on both vertical sides may not satisfy the stress equilibrium”	This is an incorrect statement and suggests the writer does not understand the principles of finite element analysis. Every stress solution if converged satisfies a force balance (and stress equilibrium). If the b.c. is a stress b.c. the horizontal stress increases associated with the inability of the material to expand (because there is always more material adjacent to it) is not accounted for. A stress b.c. assumes it is a free surface with constant load - incorrect. All reservoir Geomechanics modeling (compaction, subsidence, fracturing, etc.) understands uniaxial strain b.c. is the “typical” b.c. for reservoir conditions. The stress initialization once created due to gravity loading, tectonic loading can be held in place with rollers and satisfy stress equilibrium – the FEM solution guarantees this.	Correct statement	This issue has been addressed in SIRs for the Ivanhoe Tamarack application	The RCT agrees that applying zero displacement conditions on both vertical sides rather than a stress condition is acceptable as long as the boundary is set far enough from the edge of the last steam chamber.

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RC-04Sec 4.2 p. 5 “Nonuniform steam chamber growth may increase the risk of generating stress conditions conducive to tensile failure	Typically the largest risk tensile failure above the well pairs or adjacent to the steam chamber (or the edge of pads). Conformance issues will show similar behavior, but not the same magnitude of stress changes. That is because the maximum deformation and stretching that can occur is for a well developed steam chamber. Conformance along the well will reduce the deformations in general and, therefore transfer less deformation to the caprock resulting in smaller stress changes	Soften the verbiage to postulate this may occur – it is a hypothetical statement from the AER at this point and has not been proven		The RCT's statement already includes the word "may" so the RCT does not believe there is a need to soften the verbiage.
RC-04Sec 4.3 p. 6 (and RC-05 Sec 2.2 p. 14) “Oil sands dilate under low confining stress because the sands largely consist of strong quartz grains that do not crush.”	True, but dilation is not guaranteed as the writer seems to suggest in the monitoring document (suggested that 80% of dilation is shear – this may be a valid statement only in CSS). Shear dilation can only occur at low effective stress, so shearing at higher confining stresses will not mobilize the same dilation.			The RCT believes that shallow SAGD operations may introduce low confining stresses due to relatively high injection pressures used throughout the project life.
RC-04Sec 4.3 p. 6 “Under laboratory conditions, shear dilation is evidenced by a total increase in volume of about 1 per cent”	In McMurray sand this is incorrect. It should be more like 2-6% volumetric strain increase.	Correct statement	This is well documented in University of Alberta thesis work (Chalaturnyk, Oldakowski, etc.)	The RCT intended to say that dilation would occur when the axial strain was about 1%.

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RC-04Sec 4.3 p.6 “Yet neither ABAQUS nor GEOSIM has rock constitutive laws that are capable of accurately modelling oil sands dilation for shallow SAGD schemes”	This is totally incorrect and suggests the writer does not understand the capability of either simulator. Geosim has an elasto-plastic model that is specifically designed to model the complex dilation behavior of the oil sands. The EP model was specifically added to model over consolidated behavior of sands and clays.	Correct statement.	Geosim manual (available upon request) “A Geomechanical Methodology for Determining Maximum Operating Pressure in SAGD Reservoirs”, SPE 157855, presented at the SPE Heavy Oil Conference Canada held in Calgary, Alberta, Canada, 12–14 June 2012 (with A. Settari and J. Wang)	The RCT continues to believe that currently used geomechanical simulators do not have rock constitutive laws that are capable of accurately modelling oil sands dilation.
RC-04Sec 4.3 p. 6 “All the geomechanical models submitted to the AER to date did not take this factor into account, which could underestimate the potential for tensile failure”	True, but these materials typically are also very over consolidated. So, the unloading modulus should be similar to the loading modulus until the OCR is reached, which could be significantly above the initial stresses. If the lab testing was done properly it should verify this with initial cyclic loading of the samples to ensure limited disturbance effects. Also, if EP models are used for the oil sand and caprock (which is standard now for Geosim modeling), the unloading elastic modulus is always less than the loading modulus, if it had some plastic deformation associated with it.	Correct statement such that if EP models are used with a stiffer elastic modulus this is accounted for. Statement is a bit hypothetical at this point.		The RCT acknowledges that an EP model used with a stiffer elastic modulus can partly account for the difference between the unloading and loading Young’s modulus of the caprock.

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RC-04Sec 4.4 p. 7"In practice, the coupling terms cannot be easily treated in a system with two discretization methods."	This is not correct. Settari and Walters (2003) have published how this coupling can be easily achieved if low order elements are used in the FEM.	Correct statement	Settari, A. and Walters, D.A.: "Advances in Coupled Geomechanical and Reservoir Modeling With Applications to Reservoir Compaction", SPE Journal, Vol. 6, No. 3, Sept. 2001, pp. 334-342.	The RCT continues to believe that in practice, the coupling terms cannot be easily treated in a system with two discretization methods.
RC-04Sec 4.4 p.7 "GEOSIM is a two-way coupled geomechanical and reservoir simulator, but it can also perform one-way coupling"	Geosim coupling flexibility has not been fully described. The options are one-way (sequential), two-way explicitly coupled and iteratively coupled. The iteratively coupled technique has been shown equivalent to a fully coupled simultaneous solution, but retains the flexibility of the looser coupled methods (and gains in numerical efficiency)	Accurately describe Geosim capability	Geosim manual	The RCT acknowledges that Geosim has the options of one-way (sequential), two-way explicitly coupled, and iteratively coupled. Theoretically, if convergence is achieved, iteratively coupled method should give similar results as those from a fully coupled model.
RC-04Sec 5 p. 7 "As a result, the use of rock properties derived from small-scale laboratory tests tends to underestimate tensile failure"	Agreed, but the disturbance index can be used to quantify this effect and if the Geomech model is calibrated to surface heave or reservoir dilation it verifies the field scale material models to some extent. Also, log derived dynamic stiffness values can give us an upper bound on the material properties and provide info. for uncertainty range.	Provide a more accurate description of the risk. Suggesting an uncertainty analysis must be used to account for potentially higher stiffness values than what measured in lab.		The RCT continues to believe that laboratory tests tend to give lower values of stiffness than actually exist in situ due to sample disturbance and therefore underestimate the potential for tensile failure.

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RC-04Sec 5 p.7 "As a result, rock mass properties remain an area of particular uncertainty (Jing, 2003)."	True. However, the inclusion of the fractures in situ in the rock mass properties would typically reduce the stiffness of the equivalent continuum. So, the "disturbed" lab values may be closer to reality than initial thought. Also, Geosim has an equivalent continuum material model that can be used to quantify this upscaled stiffness behavior.	Provide a more accurate statement	Geosim manual	The RCT agrees that the inclusion of the fractures in situ in the rock mass properties would typically reduce the stiffness of the equivalent continuum. Notwithstanding, the RCT continues to believe that the rock mass properties remain an area of particular uncertainty.
RC-04Sec 6 p. 8 "The characteristics of a rock mass differ from other engineering materials in that the rock mass is always, to some degree, fractured and heterogeneous, and also generally anisotropic"	Geosim has full orthotropic model. The difficulty in using it is that the lab data to calibrate this model is not typically available.		Geosim manual	The RCT acknowledges that Geosim has a full orthotropic fracture model.
RC-04Sec 6 p. 8 "The lack of information about the rock mass and fracture geometries and properties means that working with uncertainty and variability is unavoidable for numerical modelling in rock mechanics and rock engineering"	As it is in modeling any process.	This is a logical statement, but then contradicted in other sections suggesting that risk based approaches cannot be used because there are too many variables affecting the solution.		The RCT is not suggesting that risk based approaches cannot be used.

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RC-04Sec 6 p.8 “the MOP formula provides an alternative to modelling”	The MOP formula is also a model. It is just a very simple model with many assumptions. No stress change from initial Instantaneous pressure communication between the well and caprock. No net pressure required for tensile fracturing (disregard fracture mechancis) Why can a numerical model that can relax some of these assumptions not be used to calculate a better estimate of MOP?	Suggest the gap be bridged between the MOP formula (model) and more realistic models. Maybe a bridge of the gap needs to be requested moving from the model the AER is comfortable with (MOP formula) and current technology step-by-step relaxing the assumptions..		With respect to tensile failure, the RCT believes the MOP formula provides a more acceptable level of risk, considering the limitations of geomechanical modelling.
RC-01Sec 5p. 4 Currently used geomechanical models do not have rock constitutive laws that are capable of accurately modelling oil sands dilation.	Incorrect statement	correct	Geosim manual “A Geomechanical Methodology for Determining Maximum Operating Pressure in SAGD Reservoirs”, SPE 157855, presented at the SPE Heavy Oil Conference Canada held in Calgary, Alberta, Canada, 12–14 June 2012 (with A. Settari and J. Wang)	The RCT continues to believe that currently used geomechanical simulators do not have rock constitutive laws that are capable of accurately modelling oil sands dilation.
RC-01Sec 5p. 4 Currently used geomechanical models do not take into account the difference between the unloading and loading Young’s modulus of the caprock. This may	This is incorrect if EP models are used or NLE with hysteresis. The behavior hypothesized is also not fully justified, but more of a hypothetical.	Provide proper rational rather than hypothetical		The RCT acknowledges that an EP model used with a stiffer elastic modulus can partly account for the difference between the unloading and loading Young’s modulus of the caprock.

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RC-01Sec 5p. 4 “Industry practice is to use one-way, explicitly coupled or two-way, iteratively coupled geomechanical and reservoir models rather than fully coupled models. Fully coupled models would give more accurate MOPs”	A somewhat hypothetical statement. Taurus has done some comparisons between explicit and iteratively coupled modeling. However, the AER provides no evidence this statement is true.	Provide proper rational rather than hypothetical		The RCT acknowledges that theoretically, if convergence is achieved, iteratively coupled method should give similar results as those from a fully coupled model.
RC-01Sec 5p. 4 Using rock properties derived from small-scale laboratory tests tends to underestimate the potential for tensile failure.”	Again a hypothetical statement. Taurus has seen some lab data that is almost as stiff as dynamic results and other data much softer. There is still much to learn here and only encouraging more lab testing by operators will improve the number and quality of tests to assess this.	Provide proper rational rather than hypothetical		The RCT continues to believe that laboratory tests tend to give lower values of stiffness than actually exist in situ due to sample disturbance and therefore underestimate the potential for tensile failure.