**Reviewer 1**

**Please summarize the main findings of the study.**

In this work, a phase-field model of gas bubble evolution in polycrystalline UMo under elastic-plastic deformation was developed for studying the dynamic interaction between evolving gas bubble/voids and deformation. The simulation results show that 1) the effective Young’s modulus and yield stress decrease with the increase of gas bubble volume fraction; 2) the hardening coefficient increases with the increase of gas bubble volume fraction, especially for gas bubbles with higher internal pressure; and 3) the pressure dependence of Xe thermodynamic and kinetic properties in addition to the local stress state determine gas bubble growth or shrinkage.

**Please highlight the limitations and strengths**

The demonstration of the simulation results seems to lack the comparison of PF predictions with experimental and/or analytical results.  
  
The strength lies in the ability to establish a phase field model describing the interaction between bubble evolution and elastoplastic deformation for the polycrystalline UMo. The advantages of the phase field model in simulating the influence of bubble volume fraction on elastoplastic properties and the effects of elastoplastic deformation on bubble growth dynamics are clearly depicted.

**Please comment on the methods, results and data interpretation. If there are any objective errors, or if the conclusions are not supported, you should detail your concerns**

The coupling of KKS phase field and the FFT-based elasto-plasticity is very successful, while cluster dynamics is mentioned in the section 2 but none are performed in the manuscript.  
The PF results should be compared with more experimental and/or analytical results.  
Vacancy enrichment is mentioned and highlighted in the conclusion, but the evolution of vacanciest is not directly dealed with in the manuscript.

**Please provide your detailed review report to the editor and authors (including any comments on the Q4 Check List)**

This is a very interesting work on a recent development to investigate the interaction between bubble evolution and elastoplastic deformation in UMo nuclear fuel by phase field model. In the reviewer's opinion, this is a relevant work that deserves to be shared with the scientific community. However, relative to the extensive efforts, the presentation of the manuscript does not comply with the standards of a publication such as in Frontiers (Q1) journals. Therefore, the reviewer suggests that the author prepare a revised manuscript based on the recommendations provided below. The following suggestions and comments should be taken into account before accepting the manuscript for publication:  
  
1. Readers might misunderstand that this manuscript will deal with the irradiation conditions and sink intensity, which are actually accomplished in the reference [24], due to the description of parameters (e.g. cli(n,r,t) ) in cluster dynamics in section 2.

**Response:** Thank the review’s comment.

In the revised manuscript, we added “In this work, we focused on the static or dynamic interaction between elastic-plastic deformation and gas bubbles. For simplicity, we assumed that interstitial concentration is low and fission gas Xe atoms occupy the vacancy or vacancy cluster sites. For a given Xe concentration, the vacancy concentration affects thermodynamic and kinetic properties such as lattice mismatch and diffusivity. So only Xe concentration is taken into account in this work.”   
  
2. What is the relationship between “less slip band formation” and “plastic deformation localization”? In the reviewer’s view, slip bands, such as Lüders bands, are often regarded as one of the characteristics of localized plastic deformation.

**Response:** In crystal plasticity theory, although dislocation slip systems are considered, the independent variable is the plastic strain tensor. In Figure 5 the flaky pattern of plastic strain () distribution indicates a band of high dislocation density. But dislocation types and specific information of dislocation structures are unknown. In addition, the results in section 5.1.1 don’t take into account the dynamic interaction of dislocations and solute atoms, such as the Portevin-Le Chatelier effect. Therefore, the bands with high plastic strain or high dislocation density are related to inhomogeneous shear stress around the gas bubbles, not related to Luders bands and PLC effects.

In the revised manuscript, we avoided the statement of slip bands because we don’t know the dislocation structures. We changed slip bands to shear stress and strain bands where shear stress or strain has a uniform and high value. We added more discussion on the effect of gas bubble internal pressure on plastic deformation and strain hardening.

3. What is the essential difference between the fourth and fifth conclusions? e.g. the vacancy enrichment environment can be also denoted as “tensile lattice environment” which is very similar with “tensile stress state”.

**Response:** Applied stress affects the pressure of gas bubbles. Tensile stress reduces the gas bubble pressure and the equilibrium Xe concentration inside gas bubbles. The vacancy enrichment in the matrix reduces the ratio between Xe and vacancy and the lattice mismatch of Xe atoms and increases the Xe diffusivity. Therefore, in the fifth conclusion, we use “promote” to describe the effect of tensile stress on Xe properties.

4. Can you give a reference or formula to calculate the changes in formation and migration energy due to the pressure P in pages 19-20 ?

**Response:** A compressive stress reduces the lattice constant which affects the energy of saddle point on the diffusion path as well as the energies of two ground states of Xe. Atomistic simulations can assess the effect of pressure on the migration energy. In our project, we are planning to study the effect of pressure on the thermodynamic and kinetic properties of Xe in UMo. While we do not have direct data for the UMo system, we cited two papers in the manuscript which established this relationship.

5.“From the color bar in Figure 5 and 6 it can be seen that both the maximum plastic strain and shear stress for gas bubbles with low pressure are larger than that for gas bubbles with high pressure.” It might be not rigorous to compare the results according to the color bars, while the color bars in fig.6 are still the same.

**Response:** The color bar is determined by the maximum and minimum values of the shear strain or shear stress in the simulation cell during the deformation for a given simulation condition. So the maximum and minimum values in the color bar can be used to compare the shear stress or strain in the simulation cell.

In the revised manuscript, we added “ The red and blue of the color bar in Figures 5 and 6 present the maximum and minimum values of shear strain (or stress) in the simulation cell during deformation for a given gas bubble structure with low (or high) pressure. Comparing the maximum values in the color bars in Figure 5 and 6, we can see that both the maximum plastic strain and shear stress for gas bubbles with low pressure are larger but more localized near the gas bubbles than that for gas bubbles with high pressure.”

6. Is there some qualitative relationship between irregular bubble shape and elastoplastic deformation as well as grain orientation?

**Response:** The formation of irregular gas bubble shape should be driven by the anisotropic diffusion flux of Xe around the gas bubble. The inhomogeneous and anisotropic stress field drives Xe diffusion. So any factors affecting the stress field may affect the formation of irregular gas bubbles. To do so we need to set up a simple polycrystal and gas bubble structure to distinguish the effect of different factors. Thank you for the comment, we will consider this in future work.

7. Miscellaneous  
The value of epsilon\_b0 is given in Table 1, whereas its meaning is not shown after it is first proposed on page 14. Additionally, the three-line style is likely to make Table 1 on page 13 more readable. The factor H on page 11 is not assigned a numerical value, which will affect the reproducibility of the manuscript. Some references need to be added, such as HPRRs on page 12.

**Response:** Thank you for the suggestion. The constant *H* in Eq. (30) is set to be  We provided the missing parameters, but kept the table format to have a compact form.

Reviewer 2

**Please summarize the main findings of the study.**

In this study, (1) a phase-field model of gas bubble evolution for polycrystalline UMo fuels has been developed, with the structures of gas bubble involved together with the constraint stresses by the cladding considered. (2) with the developed model, the effects of gas bubble structure on the macroscale mechanical responses are analyzed, and it has been demonstrated that the bubble volume fraction and bubble pressure induced residual stresses contribute to the variations of effective elastic modulus, yield strength and strain hardening coefficient. (3) with the developed model, the mechanisms of bubble growth or shrinkage have been proposed to attribute to the local stress state and the thermodynamic and kinetic properties of fission gas atoms.

**Please highlight the limitations and strengths.**

The strengths appears as the following: (1) the phase-field model is developed according to the thermodynamic frame, which can describe the underlying physical mechanisms and lay a foundation for the development of new fission gas swelling model and other models such as the effective creep models, and has the ability to reveal the coupling behavior of the fission gas swelling and matrix creep.  
  
The questions can be summarized as : (1) could the relations of vacancy diffusion and fission gas atom diffusion be clarified? （2） could the model be validated by some experimental results? （3） the bubble evolution has time-dependence, which is depending on the creep of fuel matrix? So, the crystal plastic model can be described as visco-plastic model ?

**Please provide your detailed review report to the editor and authors (including any comments on the Q4 Check List):**

1. The title of this manuscript could be changed as ".....under elastic-plastic and visco-plastic deformations......"?

**Response:** We thank the reviewer for their suggestion which can broaden the scope of this work. However, this work employed the plastic strain rate-based crystal plasticity. We would like to address the interaction between elastic-plastic deformation, diffusion, and microstructure evolution. So we want to keep the title. In the future, we will add creep mechanisms and radiation into this model.

(2) the mechanism of bubble growth or shrinkage could be interpreted more basically? depending on the pressure differences between the bubble pressure and macroscale pressure?

**Response:** The gas bubble evolution is described by the phase-field model. So the gas bubble growth or shrinkage is determined by the minimization of total free energy of the system. In our model, the effect of pressure inside the gas bubble on Xe equilibrium concentration and mobility inside the gas bubble and matrix is taken into account. So the effect of stress (or pressure) inside a gas bubble and in the matrix on gas bubble evolution is reflected in thermodynamic and kinetic properties such as chemical free energy and deformation energy. While this may be a more complex way to account for bubble evolution, we believe that it provides additional accuracy and the ability to account for a wider variety of material phenomena.

(3) In Fig.2, P is the hydrostatic stresses, not the hydrostatic pressure? and in the other planes P also exist?

**Response:** We thank the reviewer for the correction, and have made the change.

(4) In Eq.（8), a sign of dot product exists between the two gradient terms?

**Response:** Yes. Thanks.  
(5) In the text above Eq. (10), "...equations （9） and (10) ..." should be " ...equations （8） and (9)..."?

**Response:** We thank the reviewer for the careful reading and have made the correction.

(6) In Eq. (12), the last term of the left side should using the same subscripts "ij"?

**Response:** Thanks. We made the correction.

(7) In Eq.(15), the total stress tensor should be used to make the manipulation of double dot product with the Schmid tensor? not the deviatoric stress tensor?

**Response:** Thanks. We made the correction. In the literature, both total stress tensor and deviatoric stress tensor have been used. The effect should be minor for large deformations.

（8） What's the relation of Eq. (32) with Eq. (30)?

**Response:** We used Eq.(32) (yield stress of polycrystalline structure) to calculate the yield stress at different temperatures. The yield stress is used to estimate the yield stress of a single crystal in the crystal plasticity model.

In the revised manuscript, we added “Since we do not have the yield stress of single crystal UMo at different temperatures, the equation (32) is used to estimate the critical resolved stress in the crystal plasticity model. “

（9）The uints of variables in Table 1 should be expressed in roman.

**Response:** Thanks for the suggestion. We made the change.

(10) the pressures in the text should be the negative value of the average normal stresses.

**Response:** We changed the pressure definition as . So remain the text.

(11) Figs.(3)-(10) could be more clear?

**Response:** We will upload higher-resolution figures.

（12） The results in Fig.4 are obtained with the developed phase-field model, and then the elastic-plastic curves have been simulated in a smaller time increment?

**Response:** The results in Fig.4 are obtained at a low strain rate . For the results in Figure 9. The deformation is updated every 1000 diffusion steps.

(13) In Section 5.3, have the visco-plastic or creep deformations affected the gas bubble evolution? what's the contribution of vacancy diffusion? It is well known that vacancy diffusion is also the important mechanism of macroscale creep deformations. What's the contribution of solid fission product swelling?

**Response:** In this model, we focused on the interaction between deformation and gas bubble evolution. The effect of radiation and creep on gas bubble evolution were not considered in the current model. Solid fission product swelling definitely affects the stress, hence, the gas bubble evolution and creep. We are working to extend the model.  
  
(14) in the phase-field model, the chemical potentials of the matrix and gas bubble are assumed to the same, and it is reasonable?

**Response:** The phase-field model assumes that chemical gradient is the driving force of microstructure evolution. So the chemical potentials of the matrix and gas bubble are the same only when the system reaches equilibrium.

The KKS model assumed at any material point the chemical potentials of the matrix and gas bubble phases are the same. This means local equilibrium, but global is not equilibrium.

(15) In Eq.(1), the magnitude of the gradient of the order parameter should be used?

**Response:** Eq.(1) is the total free energy of the system. So the interfacial energy should be included.