BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF SOUTH DAKOTA

IN THE MATTER OF THE APPLICATION BY SCS CARBON TRANSPORT LLC FOR A PERMIT TO CONSTRUCT A CARBON DIOXIDE TRANSMISSION PIPELINE	**HP22-001** **DR. JOHN ABRAHAM INITIAL PRE-FILED TESTIMONY IN SUPPORT OF LANDOWNER INTERVENORS**

Q: Please state your name and purpose for providing testimony in these proceedings.

A: My name is Dr. John Abraham. The purpose of my testimony is to provide the PUC information helpful when considering Summit's proposed hazardous carbon dioxide pipeline through South Dakota.

Q: How did you become involved in these proceedings?

A: I was contacted by Brian Jorde who represented himself as legal counsel for many concerned South Dakota citizens and landowners. Mr. Jorde asked if I would opine as to the veracity, accuracy, and reliability of PHAST or Phast software modeling.
and render an opinion to a reasonable degree of scientific certainty or whether or not Phast generated Plume Modeling and resultant buffer distances contains accurate information that the PUC can rely upon. Specifically, when considering risks, and safety, land use and development considerations, economic, environmental, social and general welfare concerns for the directly affected landowners, persons and businesses in proximity to the proposed pipeline route, current and expected future inhabitants of the region, and the State of South Dakota, is the Phast modeling reliable and what weight should the PUC give to the data generated.

Additionally, I was told by Mr. Jorde that Summit has not shared their summary with the public or first responders or others as he was aware.

I will also discuss different approaches for calculating plumes from gas leaks. The calculations provide insight regarding how far a particular plume of gas may reach given environmental conditions and local topography. I will discuss the origins, strengths, and weaknesses of two competing approaches (PHAST modeling and CFD modeling), and why PHAST should not be used to assess risk from the rupture of a carbon dioxide pipeline.

Q: What experience, education, training, or background qualify you to provide opinions and your concerns as you have hearing?

A: In my professional capacity, I teach, consult with companies, and carry out research on a wide-range of engineering topics, in particular thermal-fluid sciences. The descriptor thermal-fluid sciences refer to the flow of heat and fluids (fluids include liquids, such as water; gases, such as air or other vapors; and supercritical fluids, such as supercritical carbon dioxide).

I teach courses to both undergraduate and graduate students on topics related to thermal sciences; among my regular teaching duties are Heat Transfer (a senior-level engineering course) and Advanced Thermal Design (a graduate-level course).

As a researcher, I have produced 272 scientific journal publications, given approximately 150 scientific presentations, written 37 book chapters, obtained 16 patents, with 5 applications in process. I have also edited 21 major works and written 3 books.

I am the Editor in Chief at two scientific journals (Numerical Heat Transfer part A and Numerical Heat Transfer part B) that specialize in numerical modeling of thermal fluid problems. I am the series editor of Advances in Heat Transfer, which is the most prestigious book series in heat transfer. I am also the series editor of Advances in Numerical Heat Transfer. As editor, my role generally relates to the assessment of incoming publications and determining whether they are suitable for publication. I have won numerous awards that are listed in my CV, and I serve on multiple editorial advisory boards.

My education, experience, training, and background is fully described in my CV of which a true and accurate copy is found in **Attachment No. 1**.

Additionally, I have been a consultant for industry for approximately three decades. In total, I have been retained by approximately 60 companies on a variety of subject matters in engineering, including the use of computational fluid dynamics (CFD). CFD refers to a technique of flow prediction. The process involves the placement of computational elements throughout the fluid region – then fluid parameters such as velocity, pressure, turbulence level, temperature, density, etc. are calculated at each of these computational elements. When the elements are reviewed as a whole, the picture of the real flow patterns becomes apparent. I have authored two recent books chapters on CFD modeling that provide a background to the method:

- *J.P. Abraham, S. Bhattacharya, L. Cheng, and J.M. Gorman, A Brief History of and Introduction to Computational Fluid Dynamics, in Computational Fluid Dynamics, edited by: Suvanjan Bhattacharya, published by IntechOpen, 2021.*

- *J. Gorman, S. Bhattacharya, J.P. Abraham, L. Cheng, Turbulence Models Commonly used in CFD, in: Computational Fluid Dynamics, edited by: Suvanjan Bhattacharya, published by IntechOpen, 2021.*

I have also published many dozens of studies that use CFD; these studies are listed in my CV.

Finally, I have been involved in numerous litigations and have been recognized, multiple times, as an expert in CFD modeling of multi-species flows.

Q: What materials and data did you review and consider prior to rendering your expert opinions provided here and where you asked to accept as true any particular facts?

A: 2022-05-26 PHMSA Failure Investigation Report - Denbury Pipeline near Satartia
2023-01-23 PHMSA 42023017NOPV_PCO_01312023_(21-199998)

2023-03-02 Denbury 42023017NOPV_Operator Response to Notice_03022023_(21-199998)

2023-03-24 PHMSA 42022017NOPV_Consent Agreement and Order_03242023_(20-176125)

2023-04-06 PST PR-4.6.22-Denbury-Enforcement_ES_KC_ES_Final3

2023-05-02 Entry for Satartia Rupture from PHMSA Accident Database

2013-10-01 PHMSA Failure Investigation Report Denbury Gulf Coast and Green Pipelines

2022-01-26 Weather data for Jackson MS and Satartia

2022-05-26 42022017 NOPV_PCO PCP_0526022_(20-176125) - Denbury Pipeline

Yes, I have been asked to assume that Summit, who has not yet publicly released its Plume/Dispersion modeling in South Dakota, has, like Navigator utilized the Phast Software model. I have been asked to assume that Summit and its agents, including Mr. John Godfrey in statements made to the Minnehaha County Commissioners regarding Summit have verified this fact.

I have also reviewed Navigator's "Heartland Greenway System Plume Modeling and Buffer Overview" as part of my involvement as an expert in that PUC Docket, but because that was provided to me confidentiality and is not directly relevant here, I do not discuss any specifics of those findings in this prepared testimony.

Q: What is the essence of your testimony here?

A: I testify her regarding shortcomings of the Phast Software model believed to be used in Summit's Plume/Dispersion Modeling and caution the PUC to rely upon conclusions drawn from Phast modeling specifically as it relates to the "buffer" distances Summit may also provide. My ultimate opinion is that Phast modeling is not the gold standard, should not be relied upon by the PUC for its review and decision making, and that it is not wise to rely upon Phast modeling to making decisions related to risk or safety or land use or effect on economic, environmental, social or general welfare concerns and doing so would be disserves to the people of

South Dakota. Relatedly I provide opinions concerning the diffusion of CO2 following a leak or rupture or unintended release event.

Q: Please describe for the Commission Phast or PHAST modeling and its weaknesses as a predictive tool, if any.

A: PHAST modeling is a simplified approach to estimate where a plume travels following a rupture or a leak. The method is discussed in publications such as Witlox and Holt, (1999) and while parts of PHAST originated earlier than this publication, the 1999 paper provides a thorough discussion.

As revealed in the 1999 paper, the PHAST model is based on wind tunnel experiments from other researchers. These wind tunnel experiments were needed to obtain parameters that were used to force the model to match experimental results (termed "tunable parameters"). It is noteworthy that actual ruptures, such as the February 22, 2020, rupture of the Denbury pipeline near Satartia, Mississippi, are not in wind tunnels and so any wind-tunnel experiments would be irrelevant for Satartia or other real-world ruptures.

PHAST was also premised assuming a horizontal release – not a rupture like Satartia where a significant portion of the CO2 was released vertically.

PHAST assumes that some plumes can take and maintain a perfectly spherical shape – and that other plumes can maintain circular cross sections as they move downstream, another feature that does not occur in real life.

Another weakness of PHAST is that it cannot account for changes in topography, which is an important factor for dense gases like CO2 or for locations like Satartia that occurred in hilly topography.

Another feature of PHAST is that the cloud moves with a single velocity as it travels with the wind – this too is an unrealistic assumption. It is noteworthy that when Witlox and Holt compared their calculations with experiments, they found errors of ~ 500% less than half a mile from the release site – with PHAST dramatically underestimating the concentration of released gases.

Other studies confirm that PHAST cannot be used to provide high fidelity plume calculations. In Witlox, Harper, and Oke, (2012), the calculations diverged from experiments after a distance of only ~ 30 m. Clearly, PHAST would be unable to calculate concentrations for a very different situation, over long distances (~1000m).

Based on my review of the enforcement documents prepared by the Pipeline and Hazardous Materials Safety Administration (PHMSA) for the Satartia rupture that a PHAST calculation was performed by Denbury prior to the Satartia rupture to determine if its pipeline posed a risk to the village. In its March 24, 2023 Consent Agreement with Denbury (available at: https://primis.phmsa.dot.gov/Comm/reports/enforce/documents/42022017NOPV/42022017NOPV_Consent%20Agreement%20and%20Order_03242023_(20-176125).pdf), PHMSA reported that "the earlier PHAST dispersion analysis was wrong." Denbury's reliance upon a dispersion model is also confirmed in PHMSA's May 26, 2022 Notice of Probable Violation (available at: https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/2022-05/42022017NOPV_PCO%20PCP_0526022_%2820-176125%29%20-%20Denbury%20Pipeline.pdf), and in PHMSA's May 26, 2022 Failure Investigation Report (available at: https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/2022-05/Failure%20Investigation%20Report%20-%20Denbury%20Gulf%20Coast%20Pipeline.pdf).

Consequently, from the information available to me, I conclude that Denbury – and unfortunately, every community where this particular pipeline was located - inappropriately relied upon a calculation approach that was known by Denbury, and its consultants, to be unable to incorporate critical factors necessary to determine the risks that its pipeline posed to Satartia and was also known to vastly under-predict downstream gas concentrations.

Q: Is there a superior or preferred alternative to PHAST that is more accurate and reliable, and if so, please describe that superior modeling technique.

A: Yes, there is. The gold-standard and more accurate modeling technique and tool is known as CFD, the computational fluid dynamics modeling referenced previously. CFD is becoming increasingly turned to for dispersion calculations (Huiru et al., 2021). This method has been effectively used and is able, for example, to handle different terrains (Godbole et la., 2018; Woolley et al., 2014; Mack and Sprujit, 2013; Liu, Godbole, Lu, and Michal, 2017).

CFD does not suffer the same weaknesses as PHAST. There are no tunable parameters that need to be carefully set. It can handle terrain and leaks that are not horizontal; it is able to simulate plumes that are not perfectly spherical or that have non-circular cross section. With CFD, the cloud does not move with a single velocity. Without these simplifications, CFD can yield more accurate calculations. Advantages of CFD over PHAST are known in the scientific community and are expressed, for example, by Liu et al., 2015.

> The above studies represent examples of the application of the three categories of dispersion models—Gaussian-based, similarity-profile and CFD-based. In general, CFD models are the most adaptable and are able to produce better prediction, as they use more detailed mathematical descriptions of the conservation principles. This allows the simulation of complex physical processes involving heat and mass transport in complicated computational domains (Pontiggia et al. 2009). The main drawback of CFD models is that they are often difficult and time-consuming to set up and run. Furthermore, detailed meteorological measurements and topographic data, which are essential inputs to the CFD model, are often unavailable. Gaussian and similarity-profile models are unable to model the flow over obstacles or across complex terrains (Sklavounos and Rigas 2004). However, their main advantage is that they are relatively easy to use and provide quick estimates of dispersion.

From Liu et al., 2015

Q: **Given that Summit is requesting PUC approval to for the perpetual location of their proposed hazardous CO2 pipeline, do you have an opinion as to if the Commission should rely upon PHAST modeling data and its generated buffer areas when deciding on the Summit Application, and if so, what is your opinion?**

A: My opinion, which is provided to a reasonable degree of professional scientific certainty is that the Commission should not rely upon PHAST modeling or the data and buffers that flawed modeling provides. CFD modeling should occur, and that modeling should be further scrutinized. The Commission would be wise to take the more robust and accurate and dynamic CFD modeling into account before approving or denying Summit's Application. PHAST modeling is known to underestimate gas concentrations and is unable to deal with a number of critical factors including but not limited to topography and turbulence. Furthermore, newer, more accurate methods are available that can provide more accurate concentration calculations. Had such CFD modeling been performed prior to approval of the Denbury Satartia pipeline, the citizens, landowners, local and state governments, and decision makers would have had more accurate data when reviewing the proposed location of the pipeline, whether to approve the route or not, whether to order additional conditions be included in an approved application, and the surrounding communities, first responders, and residents would have been empowered with the most reliable data and information to protect themselves, prepare for and mitigate the known and predictable risks of rupture, explosion, leak, and release from hazardous pipelines.

Had more accurate calculations been performed prior to the Satartia Mississippi CO2 incident, it is more likely than not true that leak risks and considerations, including advanced knowledge and awareness of the actual danger zones would have been more accurately known such that the negative fallout and effects on the residents and community would have been greatly minimized or prevented. Translating this to the current proposed Summit CO2 pipeline at issue here, the Commission, empowered with accurate data, may decide the actual risks associated with such a pipeline are simply too much for South Dakota and the residents, landowners, and businesses near the proposed route.

Q: Do you have an opinion as to buffer distances as generally determined by PHAST modeling and, if so, what are your opinions?

A: Yes, based on Phast modeling, it is more likely than not that all of Summit's stated buffer distances including, initial routing, design and operations, emergency response, and public awareness are under reported, inaccurate, and unreliable given the major decisions the Commission have to make.

Q: To the extent used by Summit, do you have an opinion as to concepts of "aspirational buffers" and "where feasible and practical" in relation to a pipeline companies proposed pipeline locating decisions, and if so, what are those opinions?

A: Buffer distances and setbacks should be driven by the best available scientific means and modeling – not corporate expediency or profit motive. If the goal is to consider the current existing residents, land uses, business, and other uses, the buffers and setbacks should not be "aspirational" they should be grounded in science and enforced to best protect both the existing inhabitants and land uses but also those reasonably expected in the future. The concept of "where feasible and practical" in terms of a pipeline companies' perspective is not the best practice. If the most accurate scientific methods are utilized and scrutinized, and if the Commission is to approve this project, I encourage them to do so only if the proposed route is located and sited in a manner to comply with all buffer zones and setbacks as dictated by the science not by corporate expediency or feasibility from the corporate lens.

Q: Have all of your opinions expressed herein been given to a reasonable degree of scientific professional certainty and been informed by your education, training, background, and experience?

A: Yes, they have, and I reserve the right to amend or modify these opinions upon presentation of any additional information that may justify such a change, if any.

Dated June 15, 2023

/s/ Dr. John Abraham

Dr. John Abraham