Good morning, thank you for the opportunity to provide testimony to this Committee. I trust that I will be able to provide some basic well construction knowledge that each of you will find useful as you investigate the events which occurred on the Deepwater Horizon semi-submersible drillship.

I sit before you today as a practicing petroleum engineer and Associate Professor of Petroleum Engineering at Texas A&M University, specializing in drilling deep, high pressure wells. I have, in the course of a twenty-plus year industry career, been involved in all aspects of designing and safely drilling deep, high pressure wells. I do not present myself as a deepwater drilling expert, as the bulk of my career has been onshore. However, I do offer myself as an expert in drilling engineering and operations management of high pressure wells in general.

The principles of well construction, blowout prevention and control, and safe operating practices are common across the onshore and offshore operating environments. While specific equipment and systems used in the deepwater offshore environment are unique and often quite different from that used onshore, the underlying purpose for which specific equipment is to be used is common to an onshore well of similar complexity. I believe that understanding a few of the basic principles that are used to plan and safely drill a high pressure well will assist you in dissecting the events that led to the Deepwater Horizon disaster.

As many of you know, oil and gas, which I will call “gas” from now on, are trapped in the microscopic pore space of subsurface rock formations. As the depth of the trapping formation increases, the pressure of the gas in the rock also increases. To complicate things, the rate at which the pressure increases is often variable and difficult to predict. If a borehole is drilled into the formation where the gas is trapped, there is a natural tendency for the gas to try to escape, or “flow” into the wellbore.

The challenge in designing and drilling a wellbore into a pressurized gas formation is to be able to prevent the gas from escaping the formation; and if it does escape, to be able to stop it from continuing to escape; and, then be able to return the wellbore to a balanced and safe condition whereby the gas remains in the formation. This leads me to a simple but fundamental concept that is used in well planning and blowout control, the concept of a “barrier”. A barrier provides a means by which gas is prevented from entering the wellbore, or if it has already entered the wellbore, from continuing to enter the wellbore and from moving up the wellbore to the surface.

In the drilling business it is standard practice to always have multiple barriers in place in the wellbore at any given time. That way if one barrier fails, another barrier is already in place to be used to stop the well from flowing in an uncontrolled manner. A “kick” occurs when gas enters a wellbore during the drilling process because a barrier has become ineffective. A “blowout” occurs when gas flows uncontrollably to the surface because all barriers have failed. The drilling industry has time tested and proven techniques for installing barriers in a wellbore. In kick situations, barriers must be used to prevent the kick from escalating to a blowout.

To safely drill a well, it is very important to routinely check the effectiveness of a given barrier. It is even more critical to install a new barrier, and test the effectiveness of that barrier, before any barrier is removed from the wellbore. There are numerous barriers that can be used, many of which may be

familiar to you. One barrier is the fluid that fills the wellbore during drilling, commonly called “mud” or “drilling fluid”. Drilling fluid is an extremely versatile barrier and is considered in most instances the first, or primary, barrier in the wellbore. Drilling fluid is very useful as a barrier because the density of this fluid can be changed to respond to changing formation pressures. The density of the fluid causes the drilling fluid to exert pressure against the formation. Increasing density causes an increase in pressure exerted against the formation, while reducing the density reduces the pressure exerted against the formation. In most instances, adjusting the density of the drilling fluid is all that is required to keep the pressures in the wellbore in balance.

Another common barrier is the high strength steel casing used in the construction of the well. Casing placed across a pressurized formation is an effective barrier, but only when used in conjunction with other barriers such as cement and some type of mechanical sealing element at the top of the casing. Casing is installed in a wellbore when the density of the drilling fluid can no longer be adjusted to exert sufficient pressure to keep the pressurized gas contained in the formation.

Cement is one of the key barriers used during the well construction process, but it is important to recognize that cement is perhaps the most difficult barrier to install and control. This is because cement is installed as a liquid but acts as a barrier as a solid. The time during which cement transitions from a liquid to a solid is critical, and the cement must be tested in place, meaning in the wellbore, as a solid in order to be a dependable barrier.

A different type of barrier is the mechanical barrier. A mechanical barrier is a device which, when deployed, physically blocks the movement of gas in the wellbore. The most common mechanical barrier is a blowout preventer. A blowout preventer is a large valve, more precisely series of valves, called the blowout preventer stack, placed at the top of the wellbore and used to stop movement of fluids into and up the wellbore.

Because piping, called the drill string, is used to drill the well, certain components of the blowout preventer stack are used to seal off the volume around the outside of the drill string. This leads to the need to also seal off the inside of the drill string by the use of smaller valves called “inside” blowout preventers or safety valves. Casing strings also require mechanical barriers, called float valves, to be installed at the bottom of the casing string.

Other components of the blowout preventer stack are used to seal off odd shaped or sized drilling tools run in the wellbore, or across the full diameter of the wellbore when no drill string is in place in the wellbore. Finally, a special valve, called the blind shear ram, is used to seal the wellbore in its entirety by cutting through the drill pipe, and possibly other piping components, and sealing the wellbore. The blind shear ram is used only in an emergency and is the last barrier against a blowout. It is very important to note that the blind shear ram will not necessarily cut though all possible piping components that may be in place in the wellbore.

The blowout preventer stack has multiple components with which to provide a barrier for given preconceived situations. Components of the stack have pressure ratings, for instance 10,000 pounds per square inch, or psi. This means that a blowout preventer component rated to 10,000 psi should be able to trap or contain wellbore pressures up to 10,000 psi, but that if pressures exceeding 10,000 psi are encountered the component cannot be expected to function properly. As with other barriers, testing the effectiveness of the blowout preventers is critical in that a non-functioning blowout preventer cannot be a barrier.

I should note at this point that the blowout preventer stack on a subsea well, as existed on the Deepwater Horizon, is an extremely complicated system, particularly in the means by which the blowout preventer is installed, tested, and operated. Blowout preventer valves are operated by hydraulic pressure; applying hydraulic pressure reliably at a water depth of five thousand feet can be a very complicated task and is an engineering marvel in itself.

An often overlooked but critical mechanical barrier exists at the junction between the casing and the blowout preventers. This junction is called the "wellhead". The wellhead system provides a mechanical barrier at the top of the outside of the steel casing and is critical in the event that cement fails to provide a barrier. Failure of a wellhead barrier can be catastrophic.

This leads us back to cement. Cement can be used as a barrier in several ways. First, cement is placed on the outside of the casing string to provide hydraulic isolation between the pressurized gas in the formation and the top of the casing string, wellhead, and wellbore.

Cement can also be used as a barrier in the form of a "plug" across the full diameter of the wellbore. When in place and tested this is considered to be a very reliable barrier. Mechanical devices such as bridge plugs and packers also act as barriers and can be used in place of cement plugs.

Failure of cement as a barrier is not in and of itself uncommon or disastrous. However, when cement fails as a barrier it is critical that a second barrier be in place and tested so as to offer the opportunity to repair the cement failure. Repairing cement failures is not uncommon, but can be time consuming and thus expensive.

I have mentioned several barriers that are commonly used to construct a wellbore in a safe and systematic manner, providing a means by which gas pressure in a formation can be safely encountered and balanced. These barriers are drilling fluid, cement, casing, the wellhead, and the blowout preventers.

As we all know we do not live in a perfect world, and often during the course of drilling a well a barrier becomes ineffective and gas enters the wellbore. In this event a second barrier, most often a mechanical barrier such as a blowout preventer, is called upon to be used to control the entry of gas into the wellbore.

As I mentioned earlier, the variation of pressure within subsurface formations is often erratic and unpredictable, and continuous adjustments of the density of the drilling fluid are required to balance the pressure in the formation. Often major adjustments to the drilling fluid density are required when a kick enters the wellbore. It is my experience that in the event of a kick on a deep high pressured well it is critical that the drill crew be able to flawlessly execute the standard procedures that the drilling industry has developed for such situations.

These procedures involve activating the blowout preventers, removing the kick from the wellbore, and then adjusting the density of the drilling fluid in order to return the wellbore to a balanced condition, in the process re-establishing the drilling fluid as an effective barrier.

For the drill crew to be able to do this, it is critical that the crew be able to recognize when a kick has occurred. Failure of a drill crew to recognize a kick in a timely manner is often disastrous. When a kick is recognized it is critical that the crew respond immediately to the kick and install a barrier, such as closing a blowout preventer valve across the wellbore or around the drill string.

In order for the drill crew to respond to a kick in a timely manner, it is imperative that certain critical parameters be continuously monitored. Since the drilling process requires the circulation of drilling fluid into the drill string and out of the wellbore, perhaps the most critical parameter to monitor is the rate at which fluid is exiting the well relative to the rate at which fluid is pumped into the well. It is a warning sign of a kick when fluid exits the well at a rate greater than fluid is entering the well.

Another warning sign of a kick is when the fluid volume in the drilling fluid holding tanks begins to increase. I cannot overstress the importance of monitoring fluid volumes throughout all phases of a drilling operation.

Only when at least two mechanical barriers are in place, and sufficiently tested, can the drilling fluid be removed as a barrier. Once again I stress the importance of testing a barrier for reliability prior to depending upon it to prevent a blowout.

The drilling industry strives to assure multiple barriers remain in place at all times during operations on a well. This reduces the possibility of a blowout caused by sequential loss of barriers. However, there remains the potential for human error to create conditions by which barriers are subjected to loads for which they were not designed. The industry has used intensive training as a means of reducing this risk, but unfortunately it has not eliminated the risk.

Drilling a deep, high pressured well is a complicated task. Drilling the same well in a deep water environment only adds to the complexity. However, deepwater wells, like any other well, can be safely drilled by insuring that multiple barriers remain in place at all times during the drilling operation.

For a blowout to occur multiple barriers must fail or be rendered useless through human error.

I hope that my testimony has provided the committee with a means to understand the barrier concept and to relate many terms such as drilling fluid, cement, casing, and blowout preventers to this concept.

I encourage the committee to continually ask themselves and interested parties whether or not multiple tested barriers were in place at all times on the Deepwater Horizon. It is my opinion that understanding all of the barriers that were in place on the Deepwater Horizon and their status at the time of the blowout will lead to a clear understanding of the disaster.

If a barrier failed, we must determine when and how it was tested, and when and how it failed; if a barrier was removed, we must ask why it was removed and determine if another barrier was put in place and tested in proper sequence. I know through extensive discussion with my peers that the drilling industry is keen to determine what happened on the Deepwater Horizon, and why it happened. Thank you very much.