In Part 1 of this article, we looked at how corrosion is a significant problem for end users, especially in the oil and gas industry, and looked at some of the hurdles encountered by ultrasonic testing (UT) technicians when scanning for internal corrosion. Phased array ultrasonic testing (PAUT) was identified as the most effective technique to be used in corrosion detection, measurement, and morphology, but has increased costs involved with it.

For the client, to send out different technicians to retest components multiple times is a very costly expense (requiring helicopters, boats, accommodation, and so on), so it is imperative that during the initial inspection the technician classifies any detected indications correctly, thus avoiding any unnecessary follow-up visits.

In Part 2 of this article, we will look at classifying indications seen on the A-scan display of the UT machine using a zero degree twin crystal probe due to its widespread availability and cost effectiveness. We will also look at two cases (as shown in Figures 1 and 2) where wall loss was reported initially as internal corrosion but was later reviewed as either inclusions or laminations after numerous follow-up inspections. Figure 1 is a glycol suction scrubber where internal corrosion was reported next to the inlet nozzle on the shell, and Figure 2 is a firewater pump start air receiver where internal corrosion was reported on the blind flange.
Figure 1. Indications adjacent to nozzle on glycol suction scrubber: (a) front view; (b) side view.

Figure 2. Indication on blind flange on firewater pump start air receiver: (a) front view; (b) side view.

Figure 3. Summary of scanning patterns.

**Pattern 1**
No internal corrosion detected
Pattern stays relatively constant throughout scan area, meaning the leading edge of the first backwall echo (BWE) remains approximately 40% of the timebase.

**Pattern 2**
Lamination detected
Leading edge of first BWE is now before 40% of the timebase. Three or more backwall echoes are seen.

**Pattern 3**
Inclusions in the parent metal
Low amplitude echoes coming up before the first BWE and not attached to the first BWE. Note that the first BWE and second BWE have not moved significantly on the timebase or with regard to the amplitude.

**Pattern 4**
Internal pitting
Leading edge of first BWE has moved slightly to the left of 40% timebase reference. Also note the loss of the second BWE. A slight reduction in the first BWE amplitude may also occur.

**Pattern 5**
Internal corrosion
Leading edge of first BWE has moved to the left of the 40% timebase reference. The more to the left the movement is, the more severe the corrosion. Also note the loss of the second BWE. A significant reduction in the first BWE amplitude is also evident. The echo has a "rounded" appearance.
Methodology

Below is a step-by-step description on how to analyze the signal:
- The UT machine must have an A-scan display.
- Connect a 3/8 in. (10 mm) diameter twin crystal 5 MHz delay line probe.
- Calibrate the timebase on the UT machine according to the company’s procedure.
- Apply couplant and place the probe on a clear area of the test piece, meaning an area with no internal corrosion.
- Set the leading edge of the first backwall echo (BWE) to 40% of the timebase by adjusting the range setting, meaning place the echo on graticule 2 of 5 horizontally.
- Set the peak of the first BWE to 80% of the full screen height (FSH) by adjusting the gain setting, meaning place the echo height at graticule 4 of 5 vertically.
- The leading edge of the second BWE will automatically fall on 80% of the timebase, since the second BWE is double the time of flight of the first BWE.
- Scan quickly in a back-and-forth motion, ensuring you cover the whole test area, and observe any changes in the echo pattern. One of five patterns may be observed, as summarized in Figure 3 with an accompanying sequence flowchart illustrated in Figure 4.

![Discontinuity classification flowchart](image)

Figure 4. Discontinuity classification flowchart.
Figure 5. Submitted reports summary for the glycol suction scrubber: (a) normal first and second BWE; (b) indication incorrectly classified as internal corrosion; and (c) indication as seen with shear waves.

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Figure 6. Submitted reports summary for the firewater pump start air receiver: (a) normal first and second BWE; (b) indication incorrectly classified as internal corrosion; and (c) multiple BWEs.

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Report Analysis

Equipment
The following is a list of equipment used in these examples:
- Ultrasonic testing machine with an A-scan display
- 5 MHz 3/8 in. (10 mm) diameter twin crystal delay line probe
- 4 MHz 3/8 in. (10 mm) diameter single crystal angle probes (45°, 60°, and 70°)
- Wallpaper paste as couplant
- IIW-type V2 calibration block
- Step wedge

Methods and Findings
Figure 5 provides a summary of inspection reports for the glycol suction scrubber. In the original inspection of the glycol suction scrubber (Visit 1), Technician A is the one who initially classifies the discontinuity as internal corrosion and does the same again in Visit 3. But in Visit 5, Technician A now classifies it as entrapped slag in the nozzle-to-shell weld. Note that in Figure 5b, although the signal moves to the left on the timebase and the second BWE has disappeared, the indication does not have the pattern of a typical corrosion echo (low amplitude and rounded). Please refer to Figure 3 (summary of scanning patterns) and Figure 4 (discontinuity classification flowchart) for further illustration of the scan patterns.

Figure 6 provides a summary of indication reports for the firewater pump start air receiver. For the firewater pump start air receiver, Technician D initially classifies the indication as internal corrosion in 2011. In 2014, Technician A also classifies the same indication as internal corrosion, but later revises this decision upon subsequent visits. The indication is typical of a lamination. Time and resources could have been spared if it was classified correctly initially. In Figure 6b, it can be seen that the indication comes up on the left of the timebase, on its own, and the first BWE is still present at 40% of the time-base. Also, in Figure 6c, we can see the multiple repeat echo pattern. Both of these key factors are indicative that the discontinuity is in fact a lamination and not internal corrosion. Please refer to Figure 3 (summary of scanning patterns) and Figure 4 (discontinuity classification flowchart) for further illustration of the scan patterns.

During the plant turnarounds, the opportunity to inspect the two vessels in this study with internal visual inspection was seized. The findings are illustrated in Figures 7 and 8. As can be seen, there was no internal corrosion present in the glycol suction scrubber (Figure 7).
The areas marked in red in Figure 7 were incorrectly classified as internal corrosion and later revised to inclusions in the weld. This nozzle is quite unusual since it has a nominal thickness much larger than the vessel shell thickness (the nozzle wall thickness was 50 mm and the vessel shell thickness was 12.5 mm). The technicians should not have made a final call on this finding without having the vessel weld details and should have consulted with other technicians.

As can be seen, there was no internal corrosion present in the firewater pump start air receiver (Figure 8). This blind flange had been incorrectly classified as internal corrosion, and then later on subsequent visits as containing laminations. The laminations finding is correct.

Conclusions
False calls of internal corrosion when there actually is none present in a vessel or pipe are a waste of valuable resources. Inclusions are present in steel from the original ingot up until the final product. Inclusions that are flattened out in steel shaping processes such as “rolling” to form plate will become laminations. Laminations and inclusions are not necessarily detrimental to the service life or strength of a part. The fewer inclusions/laminations the client wishes to have in steel, the more expensive the steel is to produce (such as vacuum degassed steel).

If numerous technicians are based in an area, then the cost-efficient option would be to have all the technicians qualified to perform conventional UT, and any areas suspected of having internal corrosion to be reevaluated by a suitably trained and certified phased array technician using phased array zero degree or phased array dual array transducers.

One way of standardizing readings among a team of technicians would be to have a master calibration block with the supervisor in addition to the calibration blocks held by each technician. Once a month, the technicians would measure the supervisor’s block to see whether they are within the company’s tolerance (for example, ±0.1 mm). This could help tremendously when multiple technicians test a component over a period of years to determine the actual corrosion rate for the condition monitoring location trending.

Client competency checks could be upgraded to include 10 samples from actual vessels that are no longer in service that contain a mixture of either laminations, inclusions, and/or internal corrosion, and some with no indications at all. The samples would be cut into 8 in. × 8 in. (200 mm × 200 mm) pieces and the wall loss side covered with a thin sheet of steel attached with screws so it can be removed later for training. The supervisor should prepare the master answer sheets by using ultrasonic and visual methods with the aid of pipe pit gauges. A phased array technique should also be used to record a permanent image of the deepest pits; this would add more reliability to the master answer sheets and makes good engineering sense. The technician would need to correctly measure the minimum remaining thickness for 8 out of the 10 samples, but if the technician classifies a lamination as internal corrosion or classifies internal corrosion as a lamination on any one of the samples, then this is grounds for further training.

As it can be seen, being able to differentiate between laminations, inclusions, and internal corrosion requires some practice, but with the right guidelines and by always referring your findings to a more experienced technician, fewer false calls will be experienced in the field.

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Ultrasonic thickness gauging isn’t limited to testing materials at normal (ambient) temperatures. Measurements can be made on materials whose surface temperature approaches 932 °F (500 °C). When working with metals, there may be times when the thickness needs to be measured during operations at elevated temperatures.

Oil refineries have requirements for periodic thickness measurements of high-temperature process piping, vessels, and tanks (primarily alloyed steel) using ultrasonic testing (UT) to monitor corrosion and other defects that can cause equipment failure.

The refining process starts with heating crude oil and putting it into a distillation column (also known as a still). In the still, diesel, gas, and other products boil off and are extracted at different temperatures. The distillation temperature for petroleum products ranges from as low as 85 °F (29 °C) to greater than 1050 °F (566 °C). These high temperatures make inspecting refinery equipment challenging.

Since the refining process runs continuously, the machinery can’t be cooled down for thickness inspections without shutting down the entire process.

Heat can complicate the accuracy and efficiency of measurements. If the wrong transducer is used, the heat can damage it and shorten its useful life; many can only tolerate temperatures up to about 125 °F (52 °C). At higher temperatures, standard transducers will eventually suffer permanent damage due to internal disbonding caused by thermal expansion. Changes in temperature also affect sound velocity and attenuation in materials, and these factors need to be accounted for when taking measurements. Because sound velocity decreases as temperature increases, thickness measurements taken at a higher temperature than that used for calibration will result in thickness values that are larger than the actual part thickness. This can lead to a false sense of security when taking safety-critical thickness measurements. For this reason, it is essential to use correctly calibrated equipment when taking high-temperature thickness measurements. The following tips will help users overcome the challenges of testing materials at elevated temperatures.

Use a High-Temperature Dual Element Transducer

High-temperature transducers fall into two categories: dual element transducers and delay line transducers. A high-temperature dual element transducer should be used to take thickness measurements of hot corroded metal with rough surfaces. Dual element transducers have an internal delay line material that serves as a thermal insulator between the active elements and the hot test surface, which enables the transducers to be in intermittent contact with hot surfaces without damaging the transducer element. It’s critical to choose a transducer that’s rated for use at the temperature of the inspection and to not exceed the recommended duty cycle of about 5 seconds of contact followed by a minimum of one minute of air cooling.

Use a High-Temperature Couplant

Special high-temperature couplants are required at temperatures greater than about 200 °F (93 °C). Most common ultrasonic couplants, such as propylene glycol, glycerin, and ultrasonic gels, will quickly vaporize if used on hot surfaces. Ultrasonic testing at high temperatures requires specially formatted couplants that will remain in...
a stable liquid or paste form without boiling off, burning, or releasing toxic fumes. Standard glycerin couplant is not rated for temperatures above 200 °F (93 °C), so using it will result in a loss of signal and potential damage to the transducer. Instead, choose a high-temperature couplant that’s rated for the temperature of the inspection. A variety of high-temperature couplants rated for temperatures up to 1250 °F (677 °C) are readily available.

At very high temperatures, even specialized high-temperature couplants must be used quickly since they can dry out or solidify and no longer transmit ultrasonic energy. Dried couplant residue should be removed from the test surface and the transducer before the next measurement.

### Increase the Gain

Sound attenuation in all materials increases with temperature. In typical fine-grain carbon steel alloys, attenuation at 5 MHz increases by more than 12 dB per -4 in. (101.6 mm) sound path (equivalent to a round-trip path of -2 in. [50.8 mm] each way) between room temperature and 930 °F (500 °C). This effect can require the use of significantly increased instrument gain when testing over long sound paths at high temperatures. Attenuation tends to increase with temperature at an even higher rate in materials such as plastics and composites. Most modern ultrasonic testing equipment features user-adjustable gain parameters. Because of the high attenuation levels associated with high-temperature measurements, it is often useful to increase the gain to attain a usable signal.

### Use Temperature Compensation Software

The velocity of sound in all materials changes with temperature. Normally, the velocity increases as the material gets colder and decreases as it gets hotter, with abrupt changes near the freezing or melting points. Velocity changes are related to changes in elastic modulus and density, and, depending on the material and temperature range, the relationship can be significantly nonlinear. According to the standard ASTM E797-95, the sound velocity of carbon steel decreases by about 1% per 55 °C or 131 °F (ASTM 2001). Measuring hot carbon steel with a thickness gauge set to the sound velocity at room temperature can lead to incorrect readings.

Figures 1 and 2 show the changes in velocity/transit time and attenuation when a 0.5 in. (12.7 mm) steel block is heated to 570 °F (300 °C). The pulse transit time increases from 4.37 µs to 4.59 µs, and an additional 18.2 dB of gain is needed to equalize the echo amplitude. The change in transit time would represent a measurement error of about +5% or 0.025 in. (0.63 mm) if the operator does not recalibrate the velocity for the hot test piece.

For maximum accuracy, users need to account for the effect of the higher temperature on the velocity of sound. To do this, users need to calibrate the gauge’s sound velocity setting to the temperature where measurements will be made. This can be tedious and difficult to accomplish, but some modern ultrasonic thickness gauges include a temperature compensation feature that, when active, automatically adjusts for the change in sound velocity based on temperature values that are entered before the inspection (see Figure 3). (Please note that some temperature compensation software uses a temperature coefficient for carbon steel. Other coefficients can be calculated for different materials.)
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To use the temperature compensation software feature, calibrate to a reference standard at room temperature and input the elevated temperature of the material being tested. The gauge will automatically compensate for the velocity change and display the temperature-compensated thickness value. This software eliminates the need to calibrate on a heated reference standard or manually calculate the temperature offset, and it provides the temperature-corrected thickness measurement in real time.

An alternative to using temperature compensation software is to measure after calibrating to a reference standard at room temperature and then input the data into a spreadsheet. After measuring the temperature of the test material, the inspector can calculate the actual sound velocity of the test material, and then use that number to convert their measured thickness readings to the correct values. This technique is not only inefficient, but the inspector will not know the true thickness of the part while the inspection is in progress and will not be able to easily identify incorrect measurements. Another less common technique is to heat a reference standard to the temperature of the test material, either by using heating elements or by holding the reference standard in contact with the test material. This technique is inefficient because it is difficult to handle a hot reference standard and because it is typically difficult to heat a reference standard up to the exact temperature of the test material. Once the standard is removed from the heating source, the temperature (and sound velocity) will change, leading to an inaccurate calibration.

Increase the Thickness Gauge’s Measurement Update Rate
Increasing the thickness gauge’s measurement update rate helps to reduce the amount of time required for the instrument to pick up a signal and the amount of time the transducer needs to be in contact with the hot surface. When taking measurements on very hot surfaces, it is recommended to use the highest measurement update rate possible to reduce the chance of damaging the transducer.

Apply Couplant to the Tip of the Transducer, Not the Surface of the Material
If couplant is applied to the surface of the hot material, it will most likely burn off before the user can make a measurement. Instead, apply an appropriate couplant to the tip of the transducer and couple it to the hot surface using firm pressure. Make sure not to twist or grind the transducer into the test surface, as this can cause transducer wear. Any dried couplant residue should be removed from the transducer tip between measurements.

Limit the Transducer Contact Time to 5 Seconds
All standard high-temperature transducers are designed with a duty cycle in mind. Although the delay line insulates the interior of the transducer, lengthy contact at elevated temperatures will cause significant heat buildup and, eventually, permanent damage to the transducer. For most dual element transducers, the recommended duty cycle for surface temperatures between approximately 194 °F (90 °C) and 797 °F (425 °C) is no more than 10 seconds of contact with the hot surface followed by one minute of air cooling. To be safe, it is typically recommended to limit contact time to 5 seconds. Note that this is only a guideline; the ratio of contact-to-cooling time becomes more critical at the upper end of a given transducer’s specified temperature range. If a valid thickness reading cannot be obtained in 5 seconds, uncouple the transducer from the hot surface, wait for the transducer to cool, apply more couplant to the tip of the transducer, and try again.

More advanced instruments enable the user to “freeze” the measurement screen. This is a key feature that can be used for high-temperature measurements since it enables the user to briefly couple onto the sample, capture a reading, press the FREEZE key, uncouple the transducer, and then make measurement adjustments to the A-scan.

Regularly Perform a Transducer Zero Calibration
It has been discussed that a material’s sound velocity changes with temperature, so as the delay lines within the dual element transducers heat up, they transmit sound at a different speed.
To compensate for this, users should periodically perform a transducer zero calibration. A transducer zero calibration compensates for electronic switching delays in the gauge, cable delays, and transducer delays. Some ultrasonic thickness gauges support an automatic transducer zero calibration function. This can easily be performed by first wiping the couplant off the face of the transducer and then pressing a designated key command. This function recalibrates the instrument to compensate for any thermal drift in the transducer.

Never Let the Transducer Get Too Hot to Hold
As a general rule, if the outer case of the transducer becomes too hot to comfortably hold with bare fingers, then the interior of the transducer is reaching a potentially damaging temperature and the transducer must be allowed to cool down before testing continues. Let the transducer cool in air or dip the face of the transducer in ambient temperature water. Users should then re-zero by performing a transducer zero calibration.

Performing ultrasonic thickness measurements on high-temperature materials poses a challenge to inspectors in many industries. However, with the correct equipment and techniques outlined in this article, it is possible to obtain accurate and repeatable thickness measurements on materials as hot as 900 °F (482 °C).

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Aaron F. Hulbert and Rachel L. Taylor were hired as a couple at Doncasters Group Ltd. and have continued to work together in radiography for the company. They also work together as chair (Rachel) and vice chair (Aaron) of the Connecticut Yankee Section of ASNT.

Q. So, how did you both first become involved in NDT? Did you meet through NDT, or did one of you come to an NDT career through meeting?

Aaron. I used to work semiconductors, and then I lost my job and I got hired on at [General Dynamics] Electric Boat. I was actually hired in welding, and before I even got into welding I was pulled out and asked if I wanted to go into NDT or inspection. I didn’t really know much about it until then, but got into it there and have stayed there ever since I started with MT and PT. Then finally I got into X-ray, and I liked X-ray a lot. I stayed there and got my Level I, II, and III.

Rachel. Actually, Aaron and I were friends at the time he was working at Electric Boat, and then I finally got my foot in the door as a pipe-fitter and then kind of wedged my way into working with the red dye penetrant and mag particle, and started from there. We both moved on and started doing X-ray together for a different company.

Q. Rachel, how did you get started in NDT?

Rachel. At least. At least.

Aaron. Yeah, a thousand X-rays a day, or no actually, per shift, I think.

Rachel. So right now, I’m actually just a Level I shooter, so I do a lot of the shooting of the parts. I’m working my way into Level II, so I’m in the process of transitioning to a reader, so I’m moving up, in a way. I still work under Aaron, so anything he needs, he tells his Level Is and Level IIs to do. I’ve been there for quite a while now; I’m one of the people who have been there the longest. So I assist with the engineers, casting—I’ll do a lot of work for them to make sure everything’s going well with the casting. I help with picking the techniques and doing special jobs.

Q. So, you both moved on to the same company?

Aaron. Yeah, I got hired on and then—because they [Doncasters] were looking for a Level I/II and a Level III—they asked me if I knew any other operators who were looking to work X-ray, and I said, “Yeah, I know one!” [both laugh] So I gave them the résumé. She actually got hired before I did! [laughs]

Q. Can you both tell me a bit about your current positions? What are the biggest differences, and what are some things that are similar?

Aaron. Right now I am what they call the “working Level III,” but I’m going to be transitioning over to what they call the “responsible Level III,” which is more of a management position. Whereas now I’m more on the floor. I interact with all the shifts—I’m the only Level III they have, so I just work with everybody. I’m usually really, really busy—she kind of does some of my work when I need her to do it! [both laugh] It’s easier that way: she knows what I want done, so I don’t have to tell her. She kind of just reads my mind. We work at a casting company, so it’s a high-volume X-ray, probably what, a thousand shots a day just about?

Rachel. At least.

Aaron. Yeah, a thousand X-rays a day, or no actually, per shift, I think.
Aaron. I’m trying to move up; she’s trying to go to an off shift. Right now we work on the same shift. Like I said, it’s easy, I get more done with her; I can show her more things that might be beyond an average Level I/II and she knows how to do it. She’s kind of like my right hand. Because I get really, really busy throughout the day, so it’s tough for me to get all the projects done that they need done, so she kind of helps me out.

Rachel. Not only that, I’m adamant about asking a lot of questions all the time, too. So, I’ll ask him questions throughout the day; I’ll ask other experienced readers and Level IIs questions throughout the day, so I understand what I’m doing and what I’m moving up into all the time. It does help him a lot; it helps a lot of the readers as well. For me personally, my work ethic is that I take pride in my work, so I always put my best into it.

Aaron. That, and also, I kind of watch over the sister company down in Alabama, so I’ve been taking a lot of trips to Alabama. So she helps me keep track of things up in Groton.

Q. So it sounds like it works out well working together as a team!

Both. Yeah.

Aaron. And they’re okay with it. They actually hired us on knowing that we were together and they actually asked us which shift we’d prefer to be on together, which was different. Not a lot of companies will do that.

Rachel. We like working together, too. [laughs]

Aaron. Yeah, people are like, “Wow, you see her all the time!” I really don’t, because I’m usually off doing meetings or whatever, so I’m not really down on the floor all the time, so I don’t really see her all day, but it kind of works.

Q. Tell me about your work with the Connecticut Yankee Section [Rachel is the chair of the Section, and Aaron is the vice chair.] How has being involved benefited you?

Rachel. I know for me, ASNT has definitely opened my eyes to a lot of different things. I didn’t realize at first how broad [NDT] really was; the different inspections. I knew there were several different types but it’s always expanding and it’s really cool, which keeps it very interesting. That’s one of the reasons why I like being involved in NDT.

Aaron. She was a little apprehensive at first [to go for the chair position], so me and a guy we work with, John Moran, encouraged her because we thought it would be a good experience for her to be the chair. She’s made quite a bit of contacts, I’d say, and learned a lot since she started.

Q. What are some of your professional goals?

Rachel. For me, I just want to keep working up. I kind of want to be in the position Aaron’s in, where he works with everything and kind of oversees everything. Eventually I want to get to that point. Like our friend John [Moran]—I kind of want to be like him ... he is just literally a walking open book of NDT, and it’s so cool to see that you can ask him any question and he can answer it.

Aaron. Basically, I just want to move up in my role I have. I was a Level III at EB, but how they handled it is different. That was the military field, and this is more of the aerospace; the rules are a little bit different. It’s more of interacting with the customers and still controlling the NDT process at the same time, so that can be a little bit of a learning [experience] for me. I’m thinking about going and finishing my engineering degree as well, if I can. I have some college experience, but I started out in engineering and then switched to business.

Q. So, what is the best part of working in NDT?

Aaron. When we worked in the sub field, it was kind of nice to be working on something that was part of our nation’s military. And now we’re building stuff for aircraft—not everybody does that. We work with some big companies, like Pratt & Whitney, which is extremely interesting. Actually, one of the engineers who works for them comes to our [Section] meetings all the time, and he always gives us advice. The things you get to do...for example, while taking a test I got to tour the Pratt & Whitney plant, which was amazing in itself. I’d never been there before.

Rachel. For me, it’s always a new adventure—I can put it that way! [laughs]

Aaron. Yeah, there’s never a dull moment. Things are always changing and building new. It’s never stagnant—no matter what NDT field you’re in, it’s always interesting.

Rachel. Yeah, there’s always something new that pops up, always something that might give you a sudden issue that you’ll walk away learning from. You’ll never ever get bored with it, ever.

Q. So, what is the most difficult part of NDT? Have you encountered different kinds of challenges, or similar challenges?

Rachel. For me, I have to push very hard to move forward. It’s almost like a rat race, I guess you could say, sometimes.

Aaron. Yeah, it can be rather a male-dominated industry, so it’s tough. I’ve got to say, she’s fought hard to get where she is and to move up; she’s fought really hard. And I always tell her, don’t give up, just keep pushing. Because there’s more need for NDT than there are people in the industry, so the need is always there.

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