Ultrasonic Pulse Echo

Model 98.0 Reference Guide

The Ultrasonic Pulse Echo (UPE) instrument system provides rapid, noninvasive interrogation of sealed containers and solid materials to aid law enforcement, border control, and customs officials in their smuggling, drug interdiction, and import/export control efforts. The UPE instrument merges the field practicality features of conventional ultrasonic field equipment and the power of the desktop PC environment to provide the user with a sophisticated inspection capability to more effectively support critical, on-the-spot decisions regarding shipment disposition and the safe transit of cargo.

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The UPE Model 98.0 Reference Guide is provided as supplemental information to the UPE's HELP UTILITY embedded into the instrument.

The Ultrasonic Pulse-Echo (UPE) instrument is a hand-held, portable, battery operated, ultrasonic instrument, designed for the rapid and non-intrusive inspection of materials and fluids. The instrument contains a 486-PC computer operating in a Windows 95 environment. The instrument allows a single inspector to rapidly and reliably detect hidden objects or compartments in liquid filled containers and solid materials including shipping drums, roofing tar kegs, and metals in-gots. The UPE can also identify or compare liquids or materials based on ultrasonic measurements, so that mislabeled containers and intentionally corrupted fluids are readily discernible. The ultra-sonic technology also determines the liquid fill level of a container.

The UPE instrument's extended penetration power allows the inspection of a wide range of commodi-ties such as greases, oils, yeast, resins, and simi-lar materials.

Basic Ultrasonics

Ultrasonics is the name given to the study and application of sound waves having frequencies higher than those which the human ear can hear. Normal adult hearing ranges from about 20 cycles per second (20 Hz) to 20,000 cycles per second (20 kHz). Sound is the mechanical vibration of particles in a medium (solid, liquid or gas). When ultrasonic energy is introduced into a medium, the physical characteristics of the medium affect how the sound energy travels in the medium. The changed or modified sound waves that are reflected back to the ultrasonic sensor are analyzed, and information about the medium can be extracted. Just like the properties of light energy, ultrasonic energy can be reflected, focused, and refracted. Sound beams emanating from the sensor are reflected (partially or totally) at any surface acting as a boundary between one medium and another. As with echo-sounding in sonar, or medical imaging, the ultrasonic pulses reflect from boundaries between differing media such as air pockets, floating objects, and cored out areas in solids, allowing inspectors to detect discontinuities in solid materials or objects and compartments within fluid filled containers.

The pitch of a musical tone corresponds to the frequency of the associated sound wave. The wavelength of a sound wave is inversely proportional to the frequency and is defined by the distance measured from “peak” to “peak” or crest-to-crest of the wave motion. Higher frequency sound waves have shorter wavelengths and lower frequency sound waves have longer wavelengths. This is important for both the detection sensitivity (resolution) and penetrating power (depth of inspection) of the sound beam. Inspectors should use higher frequencies for fluids and materials of smaller dimensions and lower attenuation, and use lower frequencies for larger containers and more attenuative materials and fluids.

	Resolution	Penetration
Higher Frequencies	↑	↓
Lower Frequencies	↓	↑

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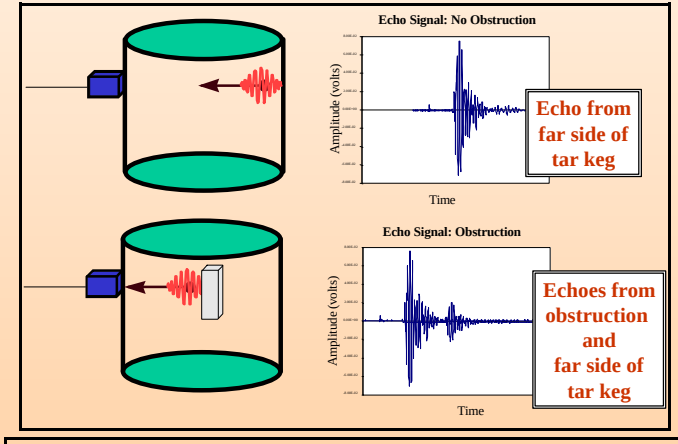
Principles of Operation

The UPE sensor head is pressed to the outside of the item under inspection and an ultrasonic pulse is introduced into a liquid filled container or a solid material. Return echoes from any reflector within the container or solid material detected by the instrument are automatically analyzed. If no reflector exists, the echo will have been reflected from the far wall, or side, of the container or solid material. Reflectors could be compartments, concealed packages, hollowed out areas in solids, or any material that differs from the actual liquid or material under test. The UPE instrument also determines the acoustic velocity in the liquid or solid material and uses this information for identification, verification, and comparison with other liquids or solids. The determination of acoustic velocity using the pulse-echo method involves measuring the time-of-flight for the ultrasonic wave, and measuring, or knowing beforehand, the distance the ultrasonic wave has traveled through the material. A tape measure or meter stick can be used for determination of the container diameter or material thickness. The UPE instrument saves this configuration information for commonly encountered containers and material forms . The presence or absence of an ultrasonic echo from the opposite side of a liquid filled container or solid material object is used by the UPE for detecting hidden contraband and determining a liquid fill level in a shipment article .



Ultrasonic echoes from kegs of roofing tar

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UPE System Description

The UPE instrument provides customs inspectors with an elegant method of screening a container's contents. It is fast and easy to use in the field, its measurement data are precise and reliable, and its PC-based design means upgrades can be easily implemented . The instrument consists of a hand-held instrument box, cables, battery pack, and remote sensor head.

The UPE's ultrasonic sensor head contains the electronics for both generating the ultrasonic pulse and for conditioning and receiving the return echoes. The sensor head accommodates both high frequency (3.5 MHz) and low frequency (120 kHz) transducers in order to support the inspection of a wide variety of liquid and solid commodities. The high frequency, 3.5 MHz, transducer is integral to the sensor head housing and the auxiliary low frequency transducer is connected directly to the UPE sensor head via a 3-pin "lemo-style" cable and receptacle.

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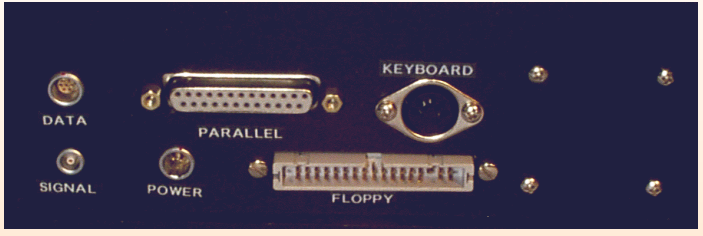
UPE Connections and Power Up



At the top end of the UPE instrument are input connection ports for a PC keyboard, a parallel port connection, a floppy drive connection, and three cable connection inputs labeled “Data”, “Signal”, and “Power”. The wall outlet power adapter and cord (3-pin female “lemo-style” adapter) connects to the “Power” input. The 7-pin male “lemo-style” connector cable connects to the base of the UPE sensor head and to the “Data” input to the UPE instrument. Finally, the 1-pin male “lemo-style” adapter cable (bundled to the 7-pin connector cable) connects to the base of the UPE Sensor Head and to the “Signal” input to the UPE instrument. The UPE instrument can be supplied with power from a wall outlet (115V, 60 Hz and 220V, 50 Hz) or via the re-chargeable Ni-Cad battery pack. The NRG Day-Pro waist-belt battery pack features dual power outputs in cigarette lighter-style with a maximum draw from both outputs of 12 amps, and a duration of 3-4 hours of continuous operation before recharging is required.

The Keyboard input allows the connection with a standard PC-keyboard for easy alphanumeric input. The Parallel and Floppy inputs are made available for trouble shooting and maintenance including instrument software upgrades.

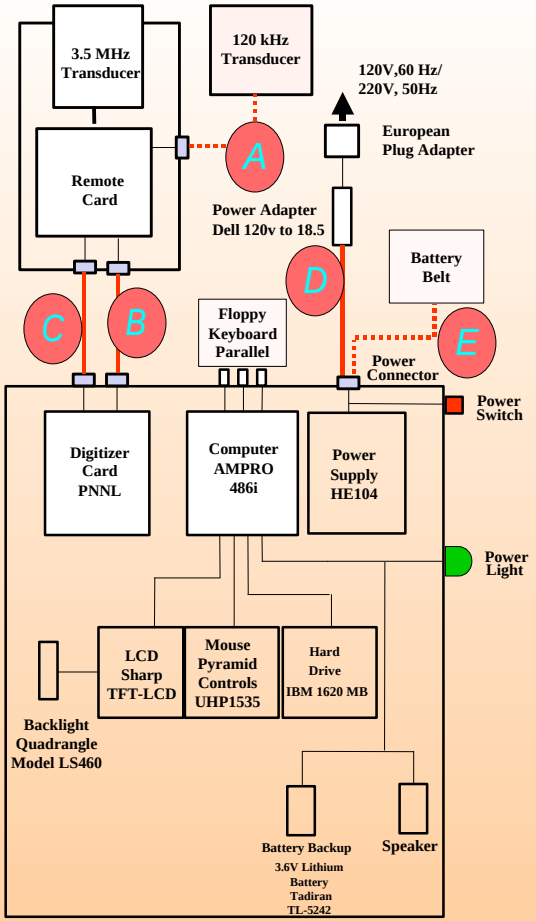
The connectors are NOT interchangeable and care must be taken when making connections that the proper cable end is being connected to the proper receptacle. The “lemo-style” connectors are labeled and color-coded to aid the operator. Care must be taken to line up the red markings on both the cable end and instrument receptacle. Do not force the cable adapters into the receptacles, as damage may result

A single two-position switch turns the instrument on and off. Do not connect or disconnect cables with the instrument powered on.

Connections and Power Up, continued

Step by Step

1. Select either HIGH or LOW frequency transducer
2. If LOW frequency transducer is selected, connect 3-pin LEMO cable A from transducer into sensor head
3. Connect "DATA" and "SIGNAL" cables between the control unit and the sensor head. The "DATA" cable B is a 1-pin LEMO and the "SIGNAL cable C is a 7-pin LEMO
4. Connect power connector to either the power adapter D or the battery pack E



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Operating the UPE Instrument

The UPE instrument is user-friendly, and can be operated simply by using the mouse. The speed and direction of the mouse pointer is controlled by pressing down (directionally) on the circular mouse pad. The harder you press, the faster the pointer will move. The UPE's top clicker-button is analogous to the right clicker button on a conventional PC mouse and the UPE's bottom clicker-button is analogous to the left clicker button on a conventional PC mouse. The center clicker-button is not used. Pointing and clicking on icons or specific command tabs invoke the function you wish to choose and rectangular shaped control-buttons on the display forms are used to set instrument parameters and initiate measurements

Step by Step

1. Select HIGH frequency or LOW frequency probe.
2. Make all connections between control unit and sensor head.
3. Connect either AC power adapter or battery belt to UPE control unit.
4. Push on power switch. Green light with indicate that the instrument is powered.
5. Wait for Windows 95 to boot.
6. Using integral mouse double-click on UPE icon to start operation.

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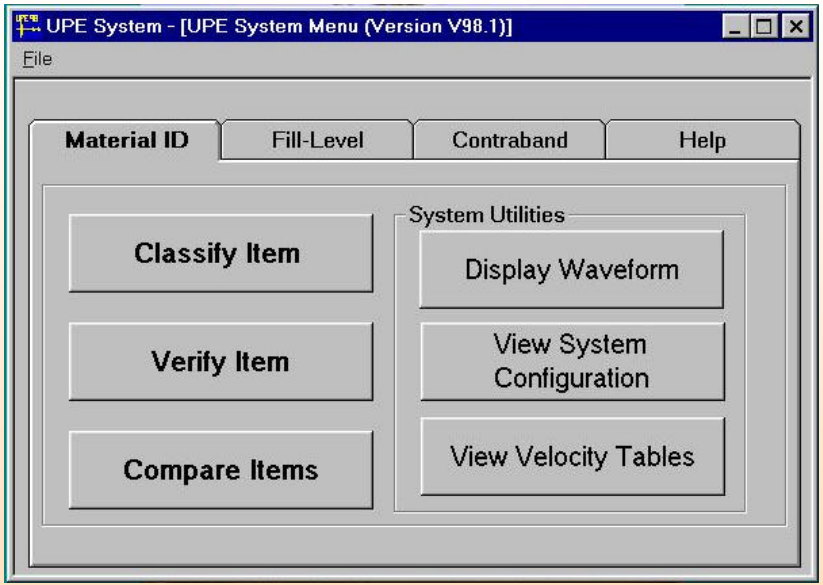
UPE Windows-based Software

The UPE instrument boots up to a Windows-95 desktop environment, with various program groups appearing as folders on the desktop. The UPE unit can be treated in the same way as a desktop PC. In order to invoke the UPE system software and begin using the instrument for an inspection, move the mouse pointer to the "UPE 98" Icon, located on the upper right portion of the desktop, and double click on the icon using the bottom mouse button. This will bring up the UPE System Main Menu. The UPE operations are organized on tabs. Simply click on the tab to initiate that specific UPE operation.

The "Classify", "Verify", and "Compare" buttons are associated with conducting a UPE interrogation and are described in this guide under the Material Identification Section. There are three system utility functions:

- Display Waveform button invokes a graphical real-time display of the ultrasonic waveform as a function of time and amplitude, with a windowed-control panel displaying various system settings.
- The View System Configuration button invokes a tabular listing of the UPE system parameters.
- The View Velocity Tables button invokes a tabular listing of currently available fluids and materials and their associated acoustic velocities in units of km/s.



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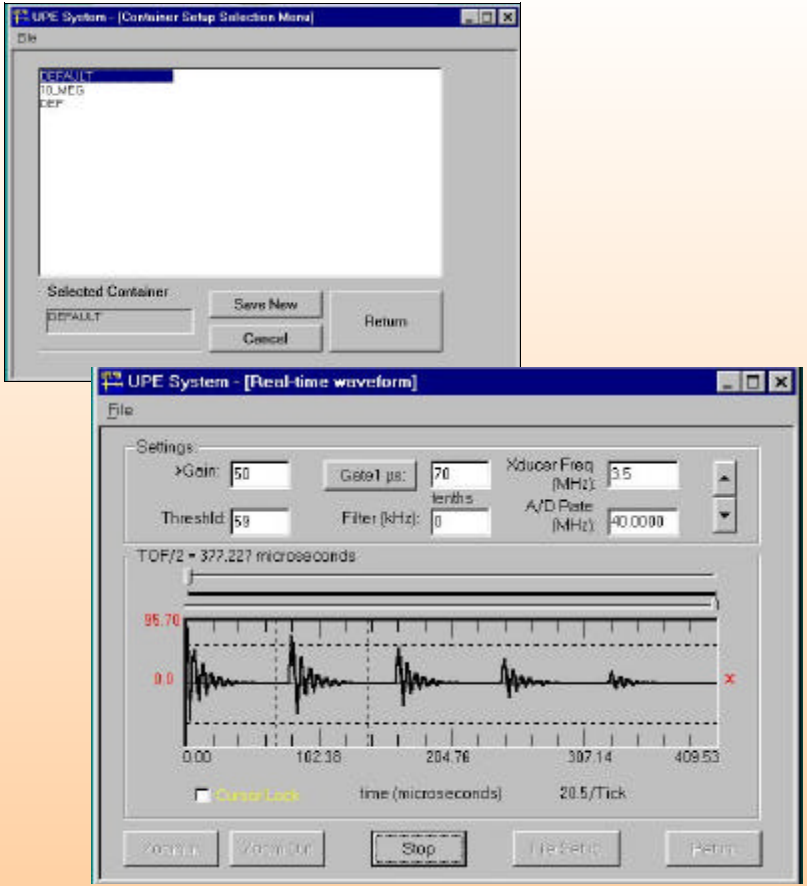
Configure UPE for Inspection

For an inspection the UPE instrument is configured for a specific material and a specific container geometry. An existing setup file is chosen while viewing the "Real-Time Waveform Display" menu.

1. **From the UPE System main menu, click on the Display Waveform button**
2. **This opens the REAL-TIME WAVEFORM DISPLAY menu**
3. **Click on the STOP button at the bottom-center of this menu**
4. **Click on the FILE SETUP button to the right of the STOP button**
5. **This opens the CONTAINER SETUP SELECTION menu which is a saved, tabular list of items.**
6. **Locate the item you wish to inspect and double click on the item**
7. **This will configure the instrument settings for inspecting the chosen item, close the CONTAINER SETUP SELECTION menu and re-open the REAL-TIME WAVEFORM DISPLAY menu.**
8. **Click on the STOP button at the bottom-center of this menu**
9. **Click on the RETURN button at the bottom-right of this menu**



Now you are back in the UPE System main menu and are ready to perform any type of inspection on the item selected.

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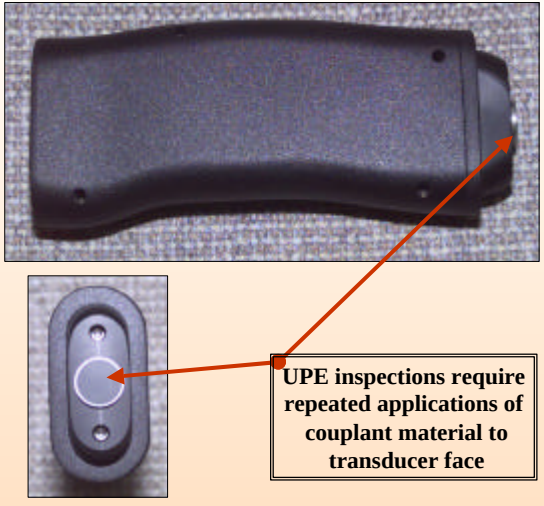
Preparing Sensor Head for Inspections

Both the HIGH and LOW frequency transducers require the application of a couplant material on the transducer front face. Both a liquid couplant and a thin flexible membrane are provided that allow ultrasonic energy to more efficiently travel into the item under test. The inspector should apply a few drops of water or ultrasonic couplant to the outer face of the transducer face (with or without the membrane covering the sensor) prior to pressing the sensor head against the test item. The inspector should make sure that the transducer head is parallel to the container wall and pressed firmly against it when examining an item. This will ensure proper coupling of energy into the item. When scanning an item, it is important to utilize a systematic approach for interrogating the entire item. If examining for fill level or contraband, the inspector should start near the bottom of the container and gradually move up along the length. Also, it is important to interrogate in the horizontal or circumferential direction at periodic intervals. This will ensure that the item under examination will be completely interrogated . Finally, it is important to firmly press the sensor head to the article being examined for approximately 2 seconds prior to moving to the next position on the article's outer surface.

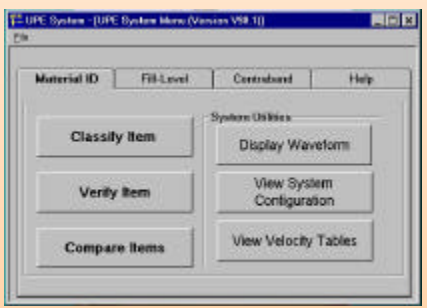


UPE Material Identification Operations

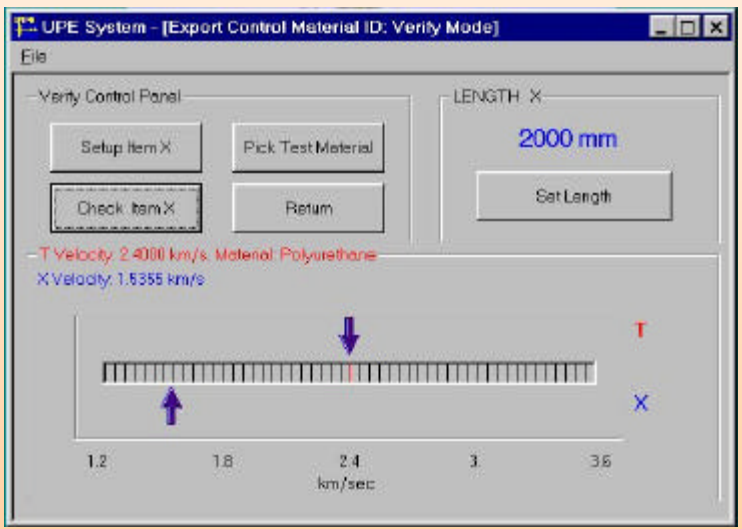
This operation suite includes:

- **Verify Item: Determine if container contents correspond to declared material on manifest**
- **Compare Items: Quickly sort shipment articles into groups of "like" and "unlike" to identify smuggling by mixed shipment**
- **Classify Item: Measure ultrasonic velocity of container contents.**

These UPE functions are initiated by clicking on the labeled buttons on the UPE Main Menu



The Verify Item mode is used when the inspector wants to determine if the measurements from the un-known contents of a container correspond to any known material measurements preserved in the UPE velocity library. To verify an item, use the bottom mouse button and click on the Verify Item button, the following menu is brought up:



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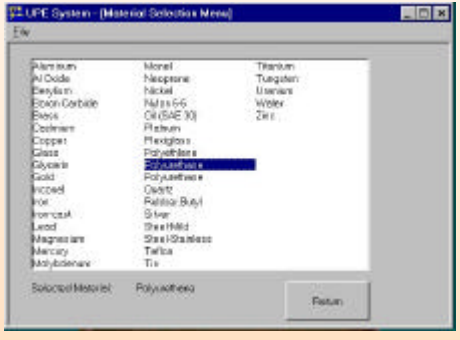
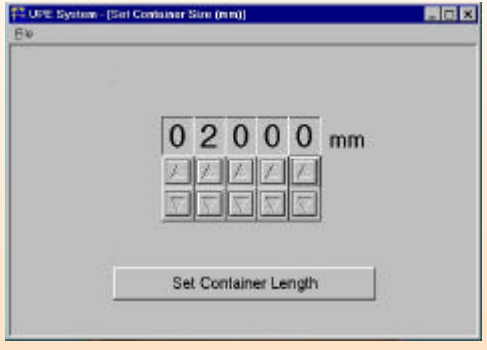
Identification Operations, continued

The operator first selects the declared material from the velocity library by clicking the mouse on the "Pick Test Material" button. A tabular listing of materials from the UPE database is displayed. Double click on the declared material in the list that you want to verify with the shipment article(s). The double click selects the material and returns to the "Verify Item" menu.



Next, the operator must measure and input the container's external dimension. The proper dimension corresponds to the path that the ultrasonic pulse will travel. For a metal shipping drum, the drum diameter is the correct dimension to measure and input. Measure the container length (in millimeters) and click on the "Set Length" button to bring up an entry keypad.

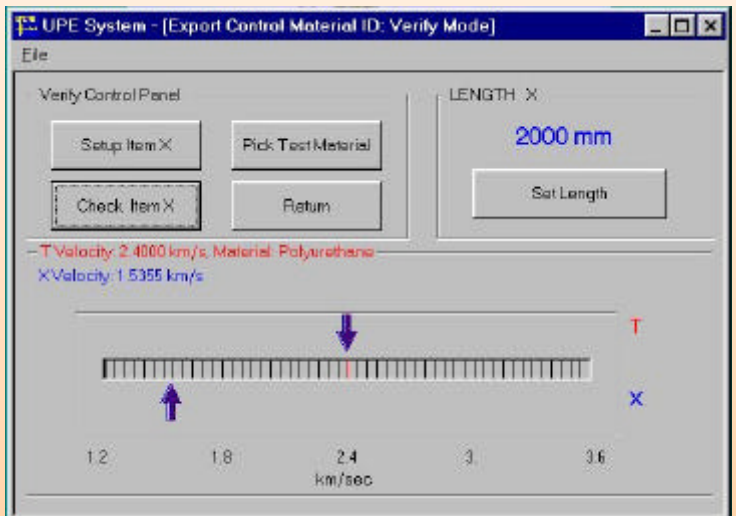
Using the UP (▲) or DOWN (▼) arrow keys enter the proper digits for container dimension and click the "Set Container Length" button. This will return you to the "Verify item" menu.



The declared material selected from the UPE data library will be represented by the "T" arrow (upper arrow, pointing down) on the display scale. The measured value from the shipment article is represented by the "X" arrow (lower arrow, pointing

Identification Operations, continued

up). If the two arrows line up (point to each other), then the shipment article is likely the material declared in the manifest. If the arrows are misaligned, the shipment article is not likely the declared material.



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Step by Step

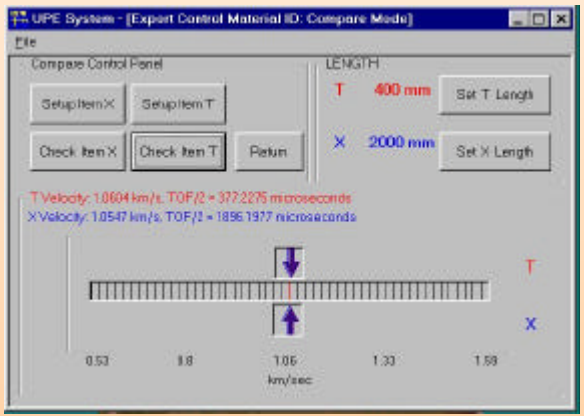
Verify Mode

1. **Based on shipment manifest documentation or other information, select declared material from UPE data base.**
2. **Input proper container dimensions using values from direct measurements or other sources.**
3. **Configure UPE system for measurement using "Setup Item X" button.**
4. **Click "Check Item X" button while holding the transducer face firmly against the container outer surface**
5. **Repeat measurement (Step 4 above) several times while observing whether the arrows align or not.**

Identification Operations, continued

The **Compare** mode is used when the inspector wants to sort articles in a shipment into groups of "like" and "unlike". This UPE mode allows the inspector to rapidly identify if contraband has been mixed among properly declared articles. The Compare mode procedure is similar to the verify mode, with the exception that the reference material is measured and is not selected from the UPE data library.

The scale display range is set by Item T measurements with the minimum value set to 50% and the maximum value set to 150% of the velocity of Item T.



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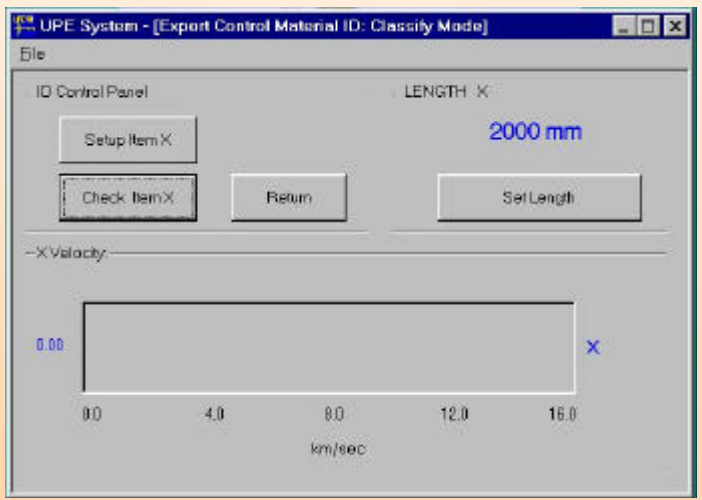
Step by Step

Compare Mode

1. Select one, or several, shipment articles to serve as a reference(s) from which to compare. This single reference article can be directly sampled to verify the identity of its contents.
2. Using "**Setup Item T**" configure the UPE and enter the proper container dimension for the reference article.
3. Click "**Check Item T**" button while holding the transducer face firmly against the container outer surface. Repeat measurement several times.
4. Using "**Setup Item X**" to configure the UPE for the remaining shipment articles. Likely the configuration is identical to that used for Item T
5. Click "**Check Item X**" button while holding the transducer face firmly against the container outer surface.
6. Repeat measurement (Step 5 above) several times for each article while observing whether the arrows align or not.

Identification Operations, continued

The Classify mode is used to make a direct ultrasonic velocity measurement of a material. This measured value may be added to the UPE material-velocity library. From the main menu, use the bottom mouse button to click on the Classify Item button.



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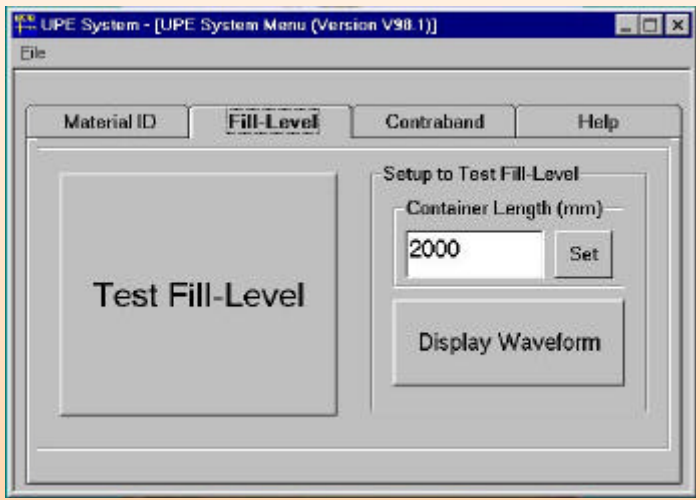
Step by Step

Classify Mode

1. **Configure UPE system for measurement using "Setup Item X" button.**
2. **Input proper container dimensions using values from direct measurements or other sources.**
3. **Click "Check Item X" button while holding the transducer face firmly against the container outer surface**
4. **Repeat measurement (Step 3 above) several times. The numerical result of the velocity measurement will appear in the upper left portion of the scale display box.**

Fill Level Determination

The UPE is designed to determine the liquid fill level of sealed containers ranging in size from soda cans to rail cars. From the main menu click on the "Fill-Level" tab display the Fill Level menu.



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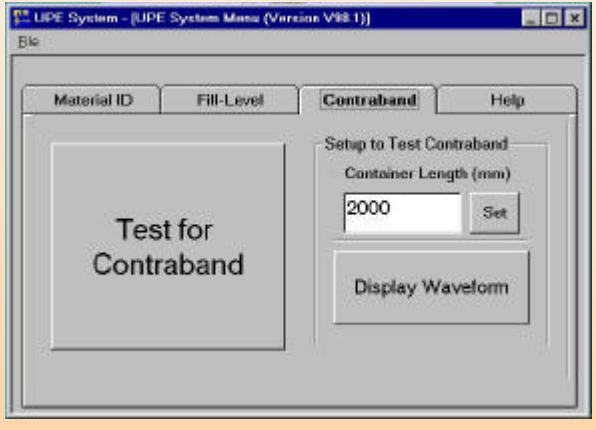
Step by Step

Fill Level Mode

1. **Configure UPE system for measurement using "Display Waveform" button. If the system has already been properly configured, skip this step.**
2. **Input proper container dimensions by clicking on the "Set" button and using values from direct measurements or other sources.**
3. **Click "Test Fill Level" button. The large button will turn red in color.**
4. **Press the transducer face firmly against the container outer surface. If the transducer is positioned above the fill level the button remains red. If it is positioned below the fill level the button turns green in color and an audible "beep" is sounded.**
5. **Repeat measurement (Step 4 above) at different points until the transducer is positioned at the point where the green and "beep" are first observed. The transducer is then positioned at the fill level. Accuracy is limited to approximately the diameter of the transducer face.**
6. **Click on the large button to stop the fill level test.**

Contraband Detection

The UPE is designed to detect the presence of concealed objects and compartments in liquid filled containers and in solid forms (metal ingots). The UPE is not designed to interrogate any container with an air gap between the outer wall and the container contents. From the main menu click on the "Test for Contraband" tab to display the contraband menu.



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Step by Step

Contraband Detection Mode

1. **Configure UPE system for measurement using "Display Waveform" button. If the system has already been properly configured, skip this step.**
2. **Input proper container dimensions by clicking on the "Set" button and using values from direct measurements or other sources.**
3. **Click "Test for Contraband" button. The large button will turn green in color and display "Testing ... click to stop".**
4. **Press the transducer face firmly against the container outer surface. If the transducer is positioned so that there is no internal obstruction between it and the container far wall, the button remains green. If there is an obstruction (contraband perhaps), the button turns red in color and an audible "beep" is sounded.**
5. **Repeat measurement (Step 4 above) until the entire container volume has been sampled.**
6. **Click on the large button to stop the contraband test.**

Saving UPE Configuration Settings

The UPE is designed to save its configuration settings for repeated use on container types that are regularly encountered at a specific port. From the Display Waveform menu, click on the "File Setup" command button to display the "Container Setup Selection Menu". Click on the "Save New" command button to display the "Save Container Setup As" display.

Use the mouse to click on the letters of the keypad display to enter a filename for the current settings. Click on "BS" (backspace) to delete the last selected character.

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Step by Step

Saving Configuration Settings

1. Enter a filename that describes a container/material combination. For example "WATER_2000MM" might appropriate for water-filled drums 2000 millimeters in diameter.
2. Click on the "Save" command button. This will save the current settings and then return to the previous display. Click the "Cancel" command button to return to the previous display without saving the settings.
3. From the "Container Setup Selection Menu", click on the "Return" command button to return to the Real-Time Waveform Display.
4. Alternately select a saved setting from the list box, and click "Return" to load that setting. To return to the Real-Time Waveform Display without changing the current settings the "Cancel" command button is clicked. Note, selecting "Return" with the "Selected Container" window containing a filename will load the settings associated with that saved file.

UPE Troubleshooting and Maintenance

The UPE has been designed to perform in the environment generally encountered at a port-of-entry. It is designed to survive the same shipment, handling, and care that a laptop-PC might experience. There are few serviceable parts on the UPE and most repairs will simply involve component replacement. The UPE is designed and fabricated at the United States Pacific Northwest National Laboratory (PNNL). PNNL is a Department of Energy laboratory located at the Hanford Site in Richland, Washington. Officials at the United States Customs Service and the United States Department of State coordinate distribution of this UPE instrument to the international community.

Design, parts, and software revisions are all keyed to the bar code labels attached to the outside of the instrument and instrument case. This label must be preserved as it serves as the sole reference from which maintenance support can be provided.

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UPE Ultrasonic Velocity Library

The UPE is provided with a library of ultrasonic velocities for a limited number of materials. The list is brief and limited to room temperature values.

Material	Ultrasonic Velocity (mm/usec)
Aluminum	6.3
Al Oxide	9.9
Beryllium	12.9
Boron Carbide	11.0
Brass	4.3
Cadmium	2.8
Copper	4.7
Glass	5.3
Glycerin	1.9
Gold	3.2
Inconel	5.7
Iron	5.9
Iron-cast	4.6
Lead	2.2
Magnesium	5.8
Mercury	1.4
Molybdenum	6.3
Monel	5.4
Neoprene	1.6
Nickel	5.6
Nylon 6-6	2.6
Oil (SAE 30)	1.7
Platinum	3.3
Plexiglass	2.7
Polyethylene	1.9
Polyurethane	2.4
Polyurethane	1.9
Quartz	5.8
Rubber,Butyl	1.8
Silver	3.6
Steel-Mild	5.9
Steel-Stainless	5.8
Teflon	1.4
Tin	3.3
Titanium	6.1
Tungsten	5.2
Uranium	3.4
Water	1.48
Zinc	4.2

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Glossary

A/D Rate:	**An instrument setting parameter that describes the increase or decrease in the analog-to-digital sampling frequency.**
Attenuation:	**The loss of acoustic energy which occurs between any two points of travel. This loss may be due to absorption, scattering, etc.**
Density:	**The measure or degree of weight per unit volume of a material.**
Excitation Pulse:	**The initial pulse of electrical energy used to excite the crystal element inside the sensor to generate the mechanical energy for acoustic inspection.**
Frequency:	**The number of complete cycles of a wave motion passing a given point in a unit time (1 second); number of times a vibration is repeated at the same point in the same direction per unit time (usually per second).**
Hertz (Hz):	**The unit of frequency measurement defined as one cycle per second.**
Impedance:	**Resistance to flow of ultrasonic energy in a medium. Impedance is the product of particle velocity and material density.**
Kilohertz (kHz):	**1000 Hertz**
km/s:	**The abbreviation for the unit of measurement for acoustic velocity, kilometers per second.**
LEMO:	**A specific type of connector fitting for cables used in the UPE ultrasonic inspection systems.**

Glossary, continued

Medium:	**The material environment (gas, liquid or solid) under examination.**
Ni-Cad Battery:	**A Nickel-Cadmium based re-chargeable battery element.**
Penetrating Power:	**The effective depth of penetration in a medium at which the ultrasonic transmission is sufficient for proper detection of discontinuities or objects.**
Pulse-Echo mode:	**An ultrasonic inspection technique where a single sensor is used for both transmission and reception of acoustic energy.**
Refracted:	**The characteristic of a material to change the direction of acoustic energy as it passes through an interface (boundary) in the refracting medium. A change in direction and velocity of acoustic energy after it has passed at an acute angle through an interface into the refracting medium.**
Resolution:	**The measure of the capability of the inspection system to separate in time two discontinuities or objects at slightly different distances.**
Sensitivity:	**The ability of the inspection system to detect small discontinuities or objects.**
Sensor:	**The search unit that consists of a housing, a piezoelectric element (crystal), backing material, wear plate, and electrical leads for converting electrical impulses into mechanical energy and vice versa. (Synonymous with transducer)**
Sound Wave:	**A periodic oscillation of particles in the medium (time series) that**

Glossary, continued

	describes the acoustic energy and that is characterized by amplitude, time and frequency.
System Gain:	**An instrument setting parameter that describes the increase or decrease in amplification of an electronic pulse associated with an ultrasonic signal.**
Threshold:	**An instrument setting parameter that allows the inspector to electronically monitor a specific segment of amplitude associated with an ultrasonic signal.**
Time-of-Flight:	**The time (usually in microseconds) it takes an ultrasonic wave to travel between two points (usually from the sensor to an interface or boundary and back to the sensor).**
Timing Gates:	**An instrument setting parameter that allows the inspector to electronically monitor a specific segment of time and /or distance associated with an ultrasonic signal.**
Transducer:	**Another term used to describe an ultrasonic search unit or sensor.**
Ultrasonic Couplant:	**A substance used between the face of the sensor (transducer) and the test surface, in order to permit or improve the transmission of ultrasonic energy across this boundary or interface.**
Ultrasonic Echo:	**A reflection of an ultrasonic wave from an interface or boundary between to mediums.**
Ultrasonic Flaw Detectors:	**Portable, electronic detection instruments that utilize ultrasound**

Glossary, continued

for flaw detection in a variety of fields and industrial applications.

Ultrasonic Signal: A digitized electronic indication captured by the ultrasonic instrument that represents any existing ultrasonic wave or disturbance, and presented in a waveform display as a function of voltage and time.

Ultrasonic (Ultrasound): Acoustic energy (mechanical sound vibrations) at frequencies above the audible range for human hearing (above about 20 kHz).

Ultrasonic Velocity: The speed at which sound waves (acoustic energy) travel through a medium

Wavelength: The distance measured perpendicular to the wavefront in the direction of propagation between two successive points in the wave, which are separated by one period. Equals the ratio of speed of sound in the medium to the fundamental frequency.