Underwater Acoustic Measurements in Megahertz Frequency Range.

Current State and Prospects of Development in Russia

Alexander M. Enyakov, VNIIFTRI

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Many medical applications of underwater acoustic measurements and effects are determined by equivalence of parameters (density, elasticity) of the water and that of human body.

Medium	Sound velocity, m/s	Density, kg/m^3	Acoustic impedance (ref. to water)
Water (20 ^{o}C)	1482	1000	1
Lung	400 – 1200	-	-
Adipose tissue	1350 – 1470	950	0,86 – 0,94
Brain	1520 – 1570	1030	1,06 – 1,09
Blood	1540 – 1600	1060	1,04 – 1,08
Liver	1550 – 1610	1060	1,11 – 1,14
Muscle	1560 – 1620	1070	1,13 – 1,18
Kidney	1560	1070	1,13
Soft tissue (mean value)	1540	1060	1,11
Bone	2500 – 4300	1200 – 1800	2,2 – 5,0
Kidney stones	1400 - 2200	850 - 1080	0,8 – 1,6

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These methods are most effective for diagnostics and treatment in the frequency range from a few to tens megahertz.

Therefore the two terms, - underwater acoustics on megahertz frequencies and medical ultrasound, - are equivalent.

IEC regulates in detail measurement methods for acoustic output and performance of ultrasonic medical equipment (UME): physiotherapy devices, diagnostic scanners, Doppler systems, lithotripters etc.

IEC standards are improved on a basis of deep research in metrology, underwater acoustics and materials. As a rule, they go ahead of the needs of medical industry.

Types of Ultrasonic Medical Equipment (UME)

Ultrasonic Diagnostics Instruments

US Pulse-echo scanners

For producing black-and-white images of many soft-tissue organs

US scanners with Doppler

For producing images with assessment of blood flow spectrum

Color Doppler Imaging Systems

For producing black-and-white and colour-flow images of many soft-tissue organs

Special Purpose Diagnostic Systems

- Hand-held Doppler foetal heart beat detectors
- US encephaloscopes
- US ophthalmoscopes

US Physiotherapy systems

For physiotherapy treatment (warming and micro-massage)

Lithotripters

For extracorporeally inducing pressure waves and disintegrating calculi and other concretions within human body

US Surgery Instruments

For aspirating or disintegrating unwanted tissue in ophthalmology, neurosurgery and dental surgery

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The UME acoustic output does not relate to its performance only, but it is also a principal safety characteristic of a device.

A basis of testing UME is the measurements of acoustic pressure parameters throughout ultrasound beam.

An acoustic pressure distribution in the ultrasound field has been examined using a planar scanning method and a hydrophone with high temporal and spatial resolution.

The total ultrasonic power measurement is also an important problem for testing ultrasonic transducers.

This parameter and its measurement methods are normalized by IEC standard for all UME.

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THE METROLOGY
OF MEDICAL ULTRASOUND IN RUSSIA

Despite the fact that medical ultrasound is an effective way of military underwater acoustics conversion, the need to develop underwater acoustic measurements on megahertz frequencies is not fully understood in Russia.

There is neither a national standard nor a hierarchy scheme for carrying out the hydrophones calibration on frequencies above 1 MHz.

Therefore we were unable to participate in BIPM Key comparison CCAUV.U-K2 (Comparison of 1 mm hydrophone calibrations in the frequency range 1 MHz to 15 MHz).

The hydrophones for measuring on frequencies up to 40 – 60 MHz are produced now in several countries, and there is IEC standard 62092 specified the hydrophone calibration in the frequency range

15 MHz to 40 MHz.

The Russian national standard covers the range up to 1 MHz only.

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ULTRASOUND: OTHER APPLICATIONS

The underwater acoustic measurements in the megahertz frequency range are not limited to the medical industry only, although it is a main consumer of these metrology services.

A research of cavitation, acoustic emission of different origin, industrial ultrasound technology, chemistry and biotechnology requires a reliable assessment of acoustic field parameters.

IEC started the development of some standards relating to these problems, e.g. ultrasound cleaning technology, focused high power radiator, etc.

TOP-PRIORITY TASKS OF DOMESTIC METROLOGY IN THE MEGAHERTZ FREQUENCY RANGE

Development of probe and membrane pvdf hydrophones (diameter of 0,1 – 1 mm) with the frequency range up to 40 MHz

Creation of national standard for the hydrophones calibration in this frequency range

Creation of primary standard of ultrasound power unit in the dynamic range from 0,1 mW to 20 W

Development of a set of reference transducers covering the frequency range of 0,5 to 25 MHz

Development of an commercially available automated device for spatial and temporal measuring of acoustic pressure in ultrasound medical fields in accordance with IEC standards

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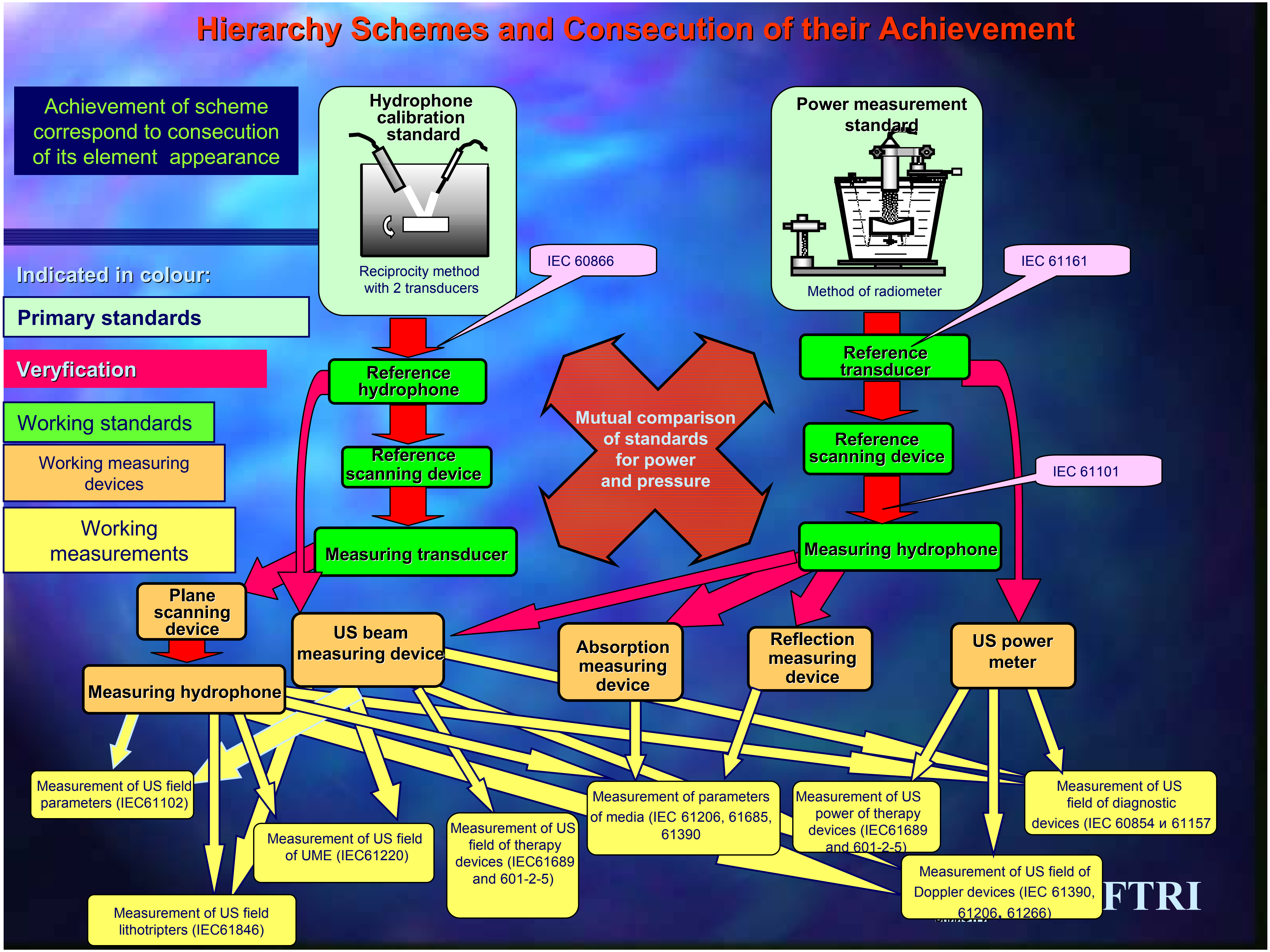

Hierarchy Schemes and Consecution of their Achievement
Achievement of scheme correspond to consecution of its element appearance
Indicated in colour:
Primary standards
Veryfication
Working standards
Working measuring devices
Working measurements
Hydrophone calibration standard
Reciprocity method with 2 transducers
IEC 60866
Power measurement standard
Method of radiometer
IEC 61161
Reference hydrophone
Reference scanning device
Measuring transducer
Mutual comparison of standards for power and pressure
Reference transducer
Reference scanning device
IEC 61101
Measuring hydrophone
Plane scanning device
Measuring hydrophone
US beam measuring device
Absorption measuring device
Reflection measuring device
US power meter
Measurement of US field parameters (IEC61102)
Measurement of US field lithotripters (IEC61846)
Measurement of US field of UME (IEC61220)
Measurement of US field of therapy devices (IEC61689 and 601-2-5)
Measurement of parameters of media (IEC 61206, 61685, 61390
Measurement of US power of therapy devices (IEC61689 and 601-2-5)
Measurement of US field of diagnostic devices (IEC 60854 и 61157
Measurement of US field of Doppler devices (IEC 61390, 61206, 61266)
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Measurements of Performance of Medical Ultrasonic Diagnostic Instruments

In order to assess and check the performance of ultrasonic scanners and Doppler systems:

- image property (dead space, penetration depth, resolution, contrast range)
- measurement accuracy of internal organs, their position and motion parameters
- measurement accuracy of blood flow parameters (mean velocity and velocity spectrum in different blood vessels)

the so-called «phantoms» are used (tissue-mimicking test-objects with fixed set of exactly located heterogeneities)

As a case in point let us consider the design of «Multipurpose Phantom, Model 539» manufactured by ATS Laboratories, Inc.

This tissue-mimicking phantom is used to evaluate the accuracy and performance of ultrasound imaging systems.

Feature: Model 539 has four acoustic windows (scanning surfaces) for probe application and possibility of imaging targets in different angles.

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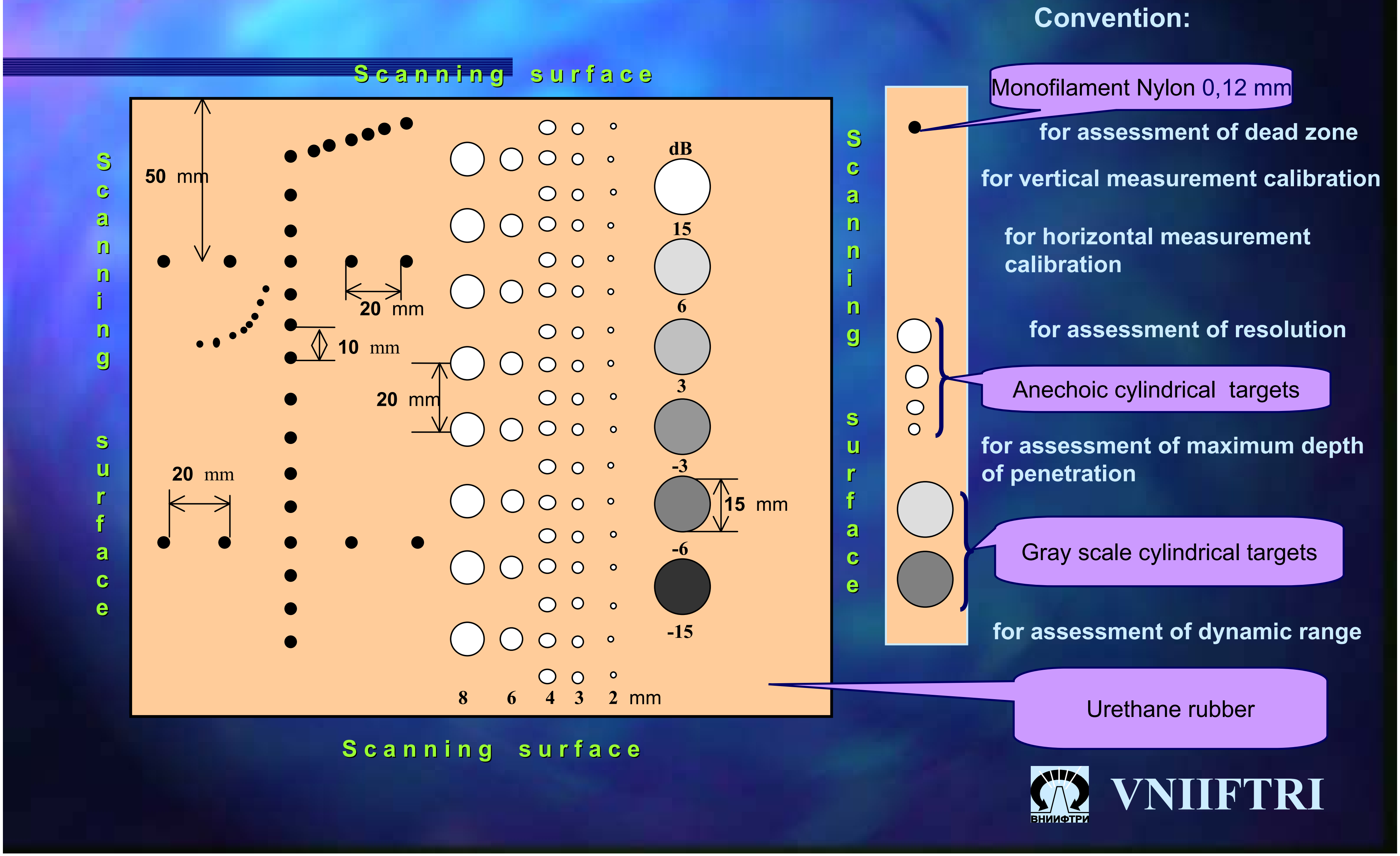
Target structures in the phantom model 539



Ultrasound Phantoms in Russia

In Russia, there is no such domestic measuring instrument. However a need for them is very large. Some foreign imported phantoms are used in few clinics occasionally, but their not verified periodically.

This is one of the causes for poor technical condition of ultrasonic devices used in some clinics in Russia.

According to the information from metrological supervision services, approximately one third of ultrasonic scanners does not meet manufacturers specification and must be repaired.

Therefore the development and production of a full set (no less than 10 types) of phantoms is very critical for domestic health protection.

Their creation demands a development of special polymeric materials with required acoustic parameters and measuring methods and instruments for measurements and verification of phantoms.

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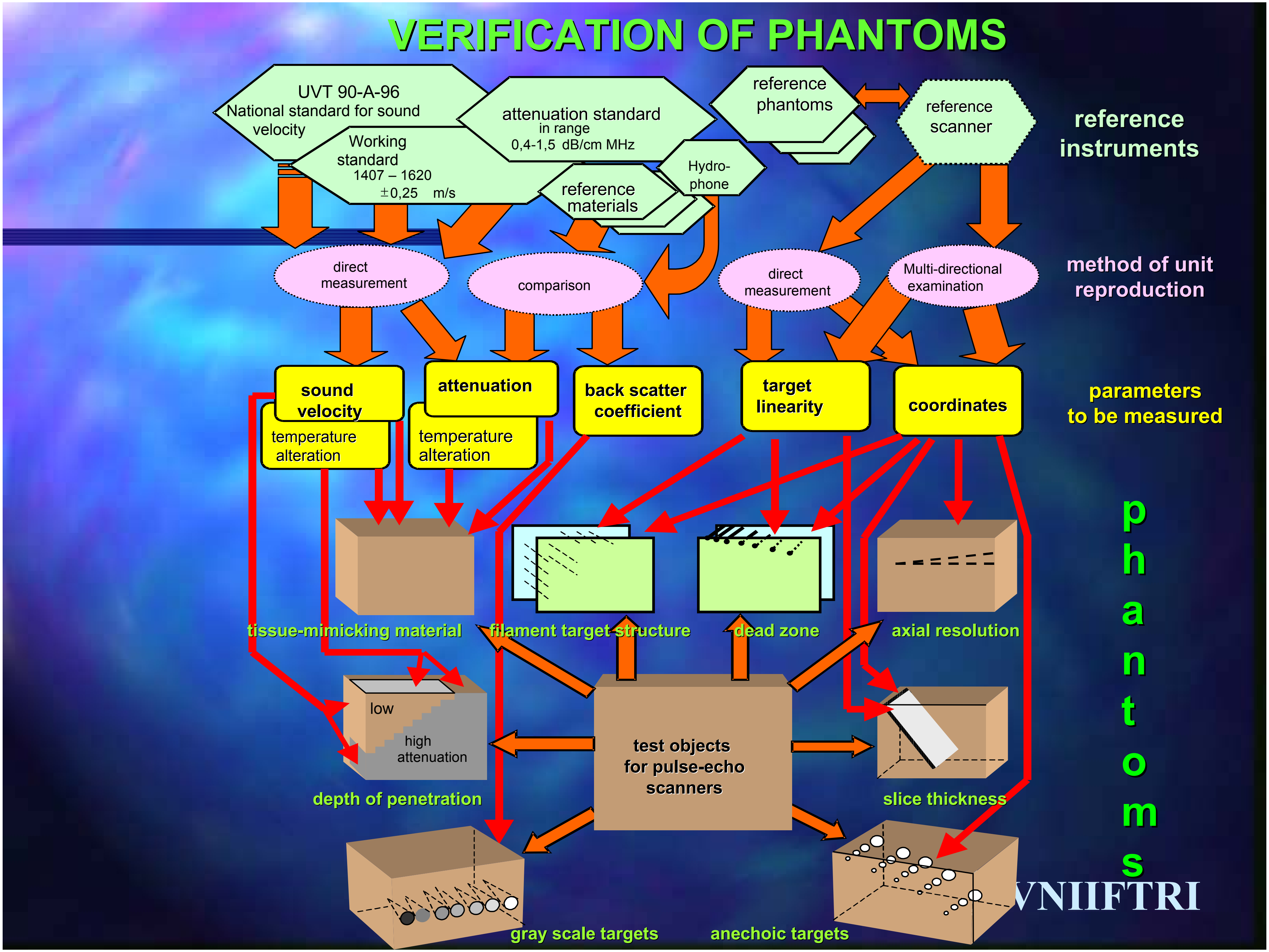
VERIFICATION OF PHANTOMS
UVT 90-A-96
National standard for sound velocity
Working standard
1407 – 1620
±0,25 m/s
attenuation standard
in range
0,4-1,5 dB/cm MHz
reference phantoms
reference scanner
reference materials
Hydro-phone
reference instruments
direct measurement
comparison
direct measurement
Multi-directional examination
method of unit reproduction
sound velocity
temperature alteration
attenuation
temperature alteration
back scatter coefficient
target linearity
coordinates
parameters to be measured
tissue-mimicking material
filament target structure
dead zone
axial resolution
low
high attenuation
depth of penetration
test objects for pulse-echo scanners
slice thickness
gray scale targets
anechoic targets
phantoms
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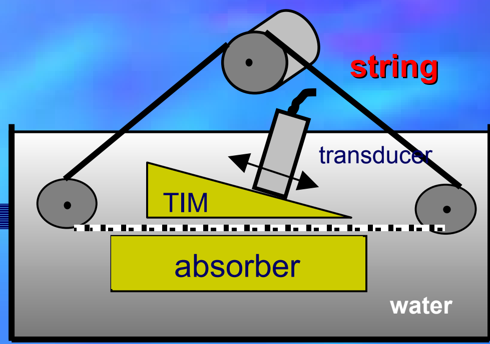
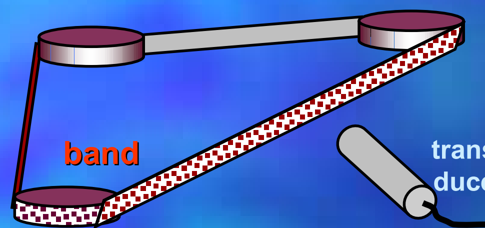
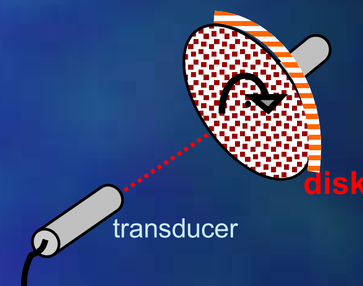
The phantoms for testing Doppler ultrasound systems simulate:



blood flow in very small blood-vessels using a string generating a single Doppler frequency

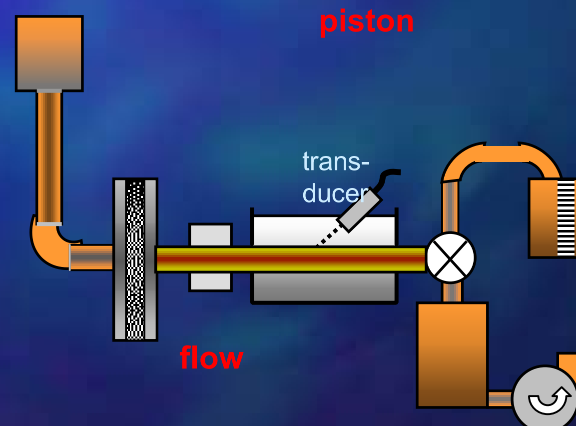
blood flow in wide blood-vessels using a band or a disk generating a single Doppler frequency





the pulsating surfaces of blood-vessels and heart, cardiac valve using the back-and-forth motions of a piston on 1 - 2 Hz

velocity spectrum of blood flow within a blood-vessel using flow Doppler test object with a parabolic profile of the flow



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Physical properties (sound velocity, attenuation coefficient, backscatter coefficient, viscosity, etc.) of phantom principal parts – target (string, band, piston, tube, blood-mimicking liquid) and medium, they are located in, must correspond to the examined tissue of human body .

For human soft tissue (average values)

Sound velocity: 1540 m s^{-1}

Density: 1060 kg m^{-3}

Attenuation: 0,5 to 1 dB cm^{-1} MHz^{-1}

For blood at 37 °

Sound velocity: 1570 to 1595 m s^{-1}

Density: 1050 to 1055 kg m^{-3}

Attenuation: 0,15 to 0,22 dB cm MHz^{-1}

Viscosity: 1,7 to 4,4 mPa s

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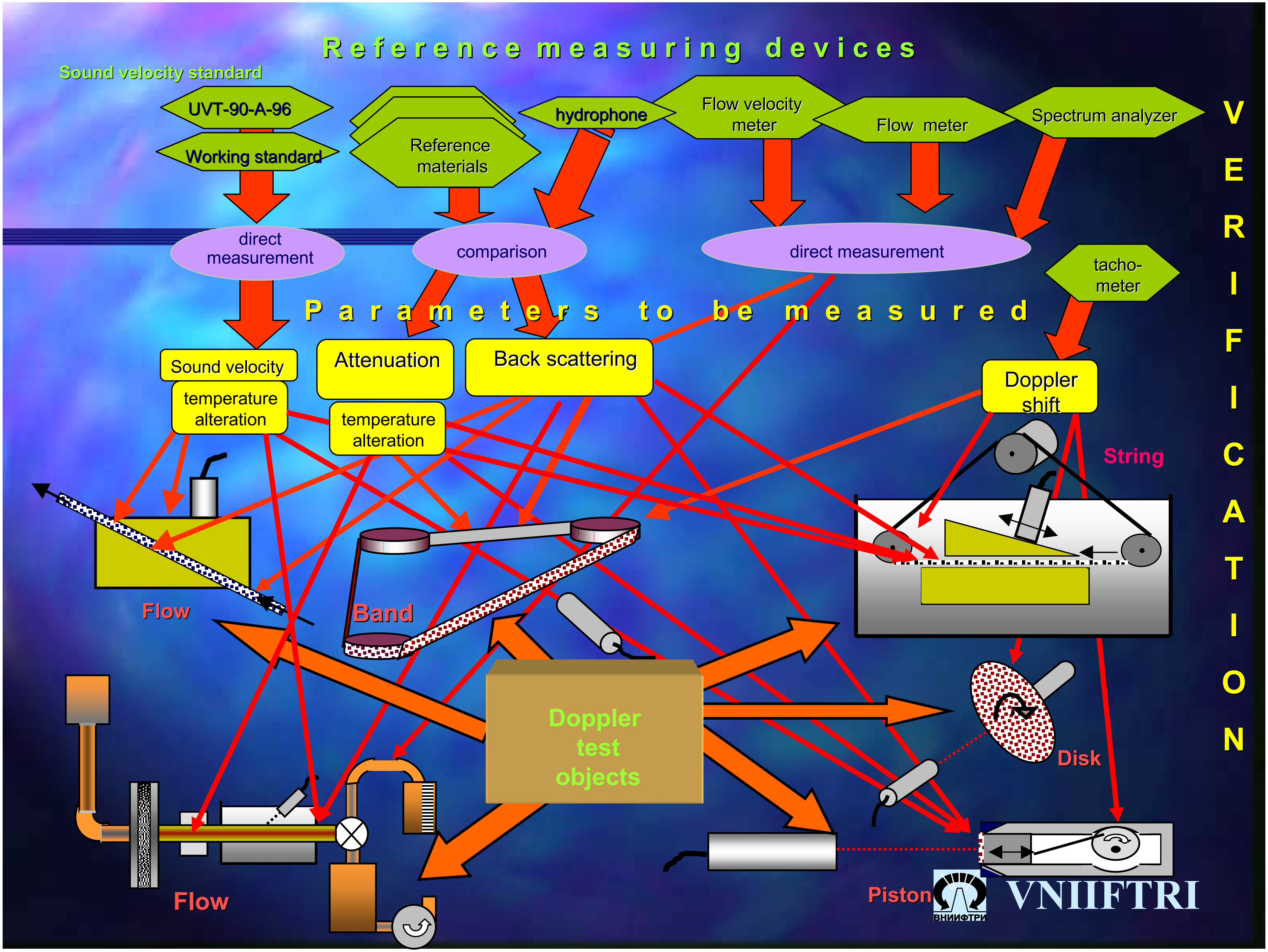
Doppler phantoms are not manufactured in Russia.

Without them, it is impossible to produce modern Doppler diagnostic instrument.

As in a case with pulse-echo scanners, the development and use of these instruments demand deep metrological maintenance illustrated by following hierarchy scheme.


Reference measuring devices
Sound velocity standard
UVT-90-A-96
Working standard
Reference materials
hydrophone
Flow velocity meter
Flow meter
Spectrum analyzer
VERIFICATION
direct measurement
comparison
direct measurement
tacho-meter
Parameters to be measured
Sound velocity
temperature alteration
Attenuation
temperature alteration
Back scattering
Doppler shift
String
Flow
Band
Doppler test objects
Disk
Flow
Piston
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C O N C L U S I O N

Russian level of development of metrology in the field of megahertz underwater acoustics is characterized by significant lagging in comparison with some foreign countries.

The necessity of development of domestic metrology and normative base for testing and quality control of medical ultrasound equipment still does not find enough understanding among medical authorities and in medical industry.

Nevertheless, our institute developed perfection tracks of metrology maintenance in the field of megahertz underwater acoustics and medical ultrasound and intends to realize it.

We determined some top-priority problems and the most necessary measuring instruments.

We developed some normative documents (about 10) harmonized with IEC standards.

We have national standard for ultrasound power in the water and developed four types of commercially available devices for measuring ultrasonic power in the water in order to testing diagnostic and therapy medical equipment.

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