Chapter 2 WHP Cruise Requirements

The requirements for all WHP sections are given in the WOCE Implementation Plan and duplicated on OCEANIC. Remaining questions on specific requirements for any WHP section should be addressed to the WHPO as far in advance of the cruise as practical.

The primary focus of this manual is on standard hydrographic measurements, water samples and CTD measurements, and the requirements for these measurements are given below. However, WHP cruises are sometimes required to make a substantial number of other measurements such as underway Acoustic Doppler Current Profiling (ADCP), bathymetry, meteorological measurements, and surface thermosalinograph data. Information about requirements for reporting these kinds of data are presented in Chapter 5.

XBTs or XCTDs are often used between hydrographic stations and the locations of such stations should be included in the —.SUM file (described in Section 3.3 on page 29). The locations of drifter and float deployments should also be noted in the —.SUM file. Current meter deployments and recoveries are another common feature of WHP cruises whose locations should be noted in the —.SUM file.

A variety of measurements made on joint WOCE/JGOFS cruises are the responsibility of the JGOFS program. However, such measurements made on water samples as part of a hydrographic cast may optionally be included in the —.SEA or —.CTD files described in this manual.

2.1 Water Sampling Requirements

2.1.1 One-Time Sections

Small volume (SV) water sampling is to be carried out on all one-time WHP sections over the entire water column. It is expected that the vertical sample interval will not exceed 200 m for each full-depth station and one sample should be taken in the surface mixed layer. Parameters to be sampled on each station cast will vary. All one-time surveys should measure at least the following parameters: pressure, ITS_{90} temperature, salinity, oxygen, and nutrients (silicate, phosphate, nitrate, and nitrite), chlorofluorocarbons (CFCs), helium, tritium and ^{14}C. CFCs should be analyzed in the upper waters and in those deep waters where CFCs are thought to occur.

The approximate amount of water presently needed for analysis of each of these samples is itemized in Table 2.1. Sampling frequencies for these parameters are not required to be identical. Only pressure, temperature, and salinity are required at every water sample level, although dissolved oxygen and nutrient analyses are strongly recommended.

We have included sampling volumes for CO_2 because it is expected that these analyses will be made on most WHP cruises in the one-time survey and on many repeat sections.

TABLE 2.1: Approximate water volume requirements for measurements drawn from small volume water samplers

Parameter	Sample Volume (cm^3)	Flush Volume (cm^3)	Total Volume (cm^3)
CFCs	100	500–1000	600–1100
Tritium[1]/He	45–90	600	690
Oxygen	150	300–450	450–600
C_T, A_T, fCO_2[2]	1000	2000	3000
^{14}C	500	500	1000
Nutrients	25	45	70
Salinity	120	180	300
Totals	1940–1985	4125–4775	6110–6760
Total for $^3H/^3He$ sample in southern hemisphere[1] 7610–9260			

Notes:

[1] Tritium collected in the southern hemisphere, 1–2 dm^3 sample volume, no flush.

[2] Sampling volumes for CO_2 are included because it is expected these analyses will be made on WHP one-time sections and on many repeat sections.

2.1.2 Repeat Hydrography and Time Series

Water sampling requirements for repeat sections may be relaxed somewhat from one-time sections. The vertical sample interval should not exceed 200 m and one water sample should be taken in the surface mixed layer on all bottle casts. Shallow casts or use of the CTD without water sampling may also qualify.

The standards for repeat hydrographic sections have been reviewed by the Core Project 1 (CP1) Working Group and are given in the CP1-4 report (WOCE Report No. 75/91, p. 5). In summary, the primary goal is to know and document the accuracy and precision of each reoccupation of a repeat line.

Repeat sections **AR01-06**, **AR17**, **IR01-06**, **PR01-11**, **PR15-25**, whose primary objectives are to look at variations in the upper ocean transport, can tolerate hydrographic data whose quality is more than an order of magnitude less than one-time survey data for some parameters. However, repeat sections **AR08-16**, **PR12-14**, and **PR26**, should be occupied to *full* WHP one-time survey standards.

Repeat sections and time-series stations **AR07**, **AR18**, **ARS10**, **PRS07-09**, whose primary objective is to look at variations in water mass properties, should achieve WHP one-time standards for all measurements, and should also be occupied with a full suite of small volume tracers.

2.2 Small Volume Water Sampling Sequence

The suggested order in which samples are to be drawn for analysis from each small volume container is given in Table 2.2. Sampling should be completed as soon as possible once a cast is on deck with dissolved gas samples collected first. The watch leader is responsible for comprehensively annotating the station log sheet to describe all relevant events, and ensuring that all samples are properly identified with regard to the sample number and bottle number from which they are drawn.

TABLE 2.2: Suggested small volume sample drawing sequence

SAMPLE DRAWING SEQUENCE
• Chlorofluorocarbons (first)
• Helium Isotopes
• Oxygen
• Fugacity (fCO_2 or pCO_2)
• Alkalinity (A_T) and pH
• Total CO_2 (C_T or DIC)
• AMS ^{14}Carbon
• Tritium
• Nutrients
• Salinity
• Pigments (last)

2.3 Large Volume Water Sampling

Large volume (LV) sampling is an integral part of the WOCE one-time hydrographic survey tracer program (Joyce, 1988). The primary LV tracer is ^{14}C. Secondary LV tracers include ^{39}Ar, ^{85}Kr, ^{228}Ra and ^{90}Sr. The relative importance of these tracers depends upon the processes and area being studied. With the exception of ^{14}C and ^{90}Sr, all of these tracers require sampling throughout the water column. Recent advances in accelerator mass spectrometry techniques need only small volume water samples in the depth range where bomb ^{14}C is present.

Except for ^{39}Ar, which requires about 1250 liters, each of the LV tracers needs sample volumes of 200-300 liters of water. The sample path is shown schematically in Figure 2.1 and is based upon experience during TTO/SAVE. This procedure may be altered somewhat depending upon proposed extractor changes. Methods for the collection and analysis of LV samples are described by Key (1991) in the WOCE Hydrographic Operations and Methods manual (WHPO 91-1).

The watch leader is responsible for ensuring that all samples drawn are properly identified with the sample and bottle number and annotating the station log sheet in the event any problems occur while collecting samples from the water bottles.

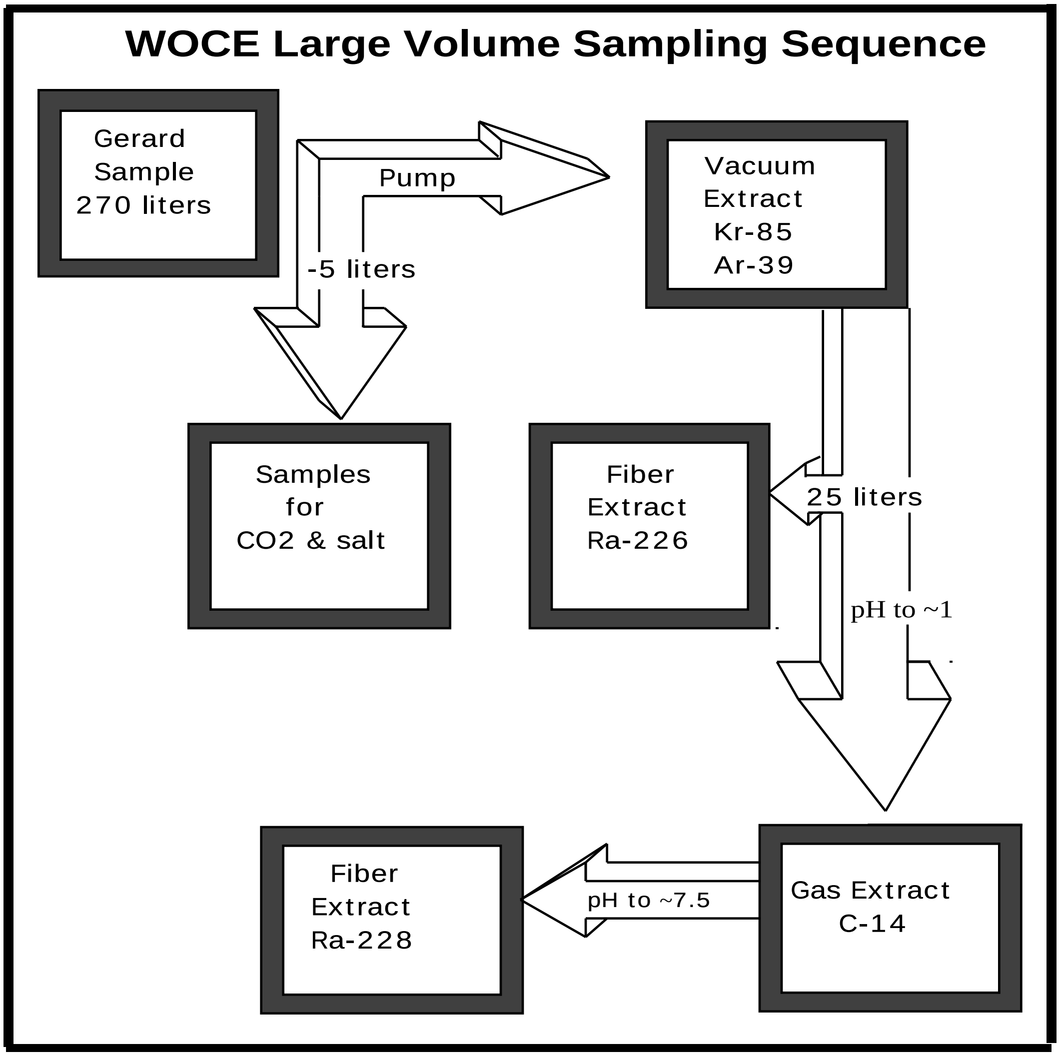

FIGURE 2.1: Large volume sample drawing sequence

2.4 Data Quality Standards

Standards for precision and accuracy of WHP hydrographic data are presented here and were originally given by Joyce (1988). In many instances, however, no absolute reference standard exists for accuracy. The figures quoted are often the *reproducibility* rather than accuracy. As measurement capabilities improve in coming years, the published standards may be routinely exceeded; thus, we have indicated some changes here, mainly in precision, from the earlier published values in the included tables in order to help stimulate greater resolution in the data.

The WOCE Hydrographic Programme seeks to acquire and assemble a uniformly accurate global data set. In order to approach this ideal it is essential that the highest standards of accuracy, reproducibility, and precision be maintained by all participating groups. Thus, it is *required* that all investigators report their results in the units specified herein; as no data base is valid if the numbers therein have inconsistent units, nor can routine checks and comparisons of the data be conveniently made. For example, dissolved gas values are to be reported in mass units, that is, *µmol/kg*, rather than the traditional volumetric units of *ml/l*. Conversions for all WOCE parameters are given in WHPO 91-1, WHP Operations and Methods (Joyce, 1991). For convenience, the International System of Units (SI) used in hydrography are reproduced in Table 2.3. Prefixes for SI units and their abbreviations are given in Table 2.4. Raw data in engineering units, such as DC volts (VDC), cannot be accepted. If there is any question as to what units are standard for the type of measurement you are making please consult with the WHPO as soon as possible.

In the interests of uniformity we also use the following definitions for accuracy, reproducibility, precision, and limits of detection:

Accuracy: Accuracy is *defined* as the extent to which a given measurement agrees with an accepted standard value for that measurement.

Unfortunately, only a few of the parameters measured in the WOCE Hydrographic Programme have international, or even national, standards available. As a secondary measure of accuracy it is possible to consider the standard deviation of interlaboratory reproducibility. This is computed from the results of a collaborative study of an analytical method involving operators in different laboratories using different apparatus for analysis of the same sample. Results of such intercomparisons are reported in manuals published by the WHPO from time to time.

Reproducibility: As used here, reproducibility is the total intralaboratory standard deviation of a series of measurements. This parameter is the maximum intralaboratory standard deviation to be expected from the performance of a method, at least on different days and preferably with different calibration curves or reagents, e.g., repeat cruises. It includes between-run as well as within-run variations. Thus, the reproducibility is always larger than the precision but it is not a measure of the accuracy of the measurement, although the two are often mistakenly used interchangeably.

Precision: Precision is *defined* as the extent to which a given set of measurements of the same sample agree with their mean. Thus, precision is commonly taken to be the standard deviation estimated from sets of duplicate measurements made under conditions of repeatability, that is, independent test results obtained with the same method on identical test material, in the same laboratory by the same operator using the same equipment in short intervals of time.

Limit of Detection: A measure of the concentration of the substance being analyzed that is significantly different from the *blank* or *background* signal. While in communication theory a level of two times the background is taken to be the limit of detection the issue is not so clear-cut with many oceanographic measurements and the exact definition of *significantly different* is open to interpretation. Recent guidelines suggest that the criterion should be three times the standard deviation of the blank.

TABLE 2.3: SI units and standard abbreviations

SI BASE UNITS		
Quantity	**Name of Unit**	**Symbol**
length	meter	m
mass	kilogram	kg
time[1]	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
luminous intensity	candela	cd
amount of substance	mole	mol
SI DERIVED UNITS		
area	square meter	m^2
volume	cubic meter	m^3
frequency	hertz	Hz (s^{-1})
mass density (density)	kilogram per cubic meter	kg m^{-3}
speed or velocity	meter per second	m/s
angular velocity	radian per second	rad/s
acceleration	meter per second squared	m/s^2
angular acceleration	radian per second squared	rad/s^2
force	newton	N ($kg \cdot m/s^2$)
pressure (mechanical stress)	pascal	Pa (N/m^2)
work; energy; quantity of heat	joule	J (N·m)
power	watt	W (J/s)
entropy	joule per kelvin	J/K
specific heat capacity	joule per kilogram kelvin	J/(kg K)
thermal conductivity	watt per meter kelvin	W/(m K)
activity (of a radioactive source)	becquerels decays per second WOCE uses decays per minute	s^{-1} dpm
SI SUPPLEMENTARY UNITS		
temperature	degrees Celsius = K – 273.15	°C
length	nautical mile = 1.852×10^3 m	nm
pressure	bar = 10^5 Pascal atmosphere = 1.01325×10^5 Pa	bar atm

1. *Note that time on WOCE cruises is always given relative to the Greenwich Meridian, that is Universal Time, or UTC.*

TABLE 2.4: Prefixes for SI units

Factor by which unit is multiplied	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

2.4.1 Measurement Standards

As yet there is no formal structure for evaluating laboratories participating in the WOCE Hydrographic Programme based on the use of replicate and blind samples and thus an estimate of the reproducibility and precision for many measurements cannot be determined at present. It has also been necessary in many cases to estimate the desired levels of accuracy, reproducibility, and precision based on the results of the most advanced groups making the measurements. The expected standards for water sample data on one-time surveys are given in Table 2.5 and for CTD data in Table 2.6. The standards for repeat hydrographic sections have been reviewed by the Core Project 1 (CP1) Working Group and are given in the CP1-4 report (WOCE Report No. 75/91, p. 5). In summary, the primary requirement is to determine and document the accuracy (or reproducibility) and precision of each occupation of a repeat line.

2.5 WHP Operations and Methods Manual

Methods are provided in a separate document, WOCE Hydrographic Operations and Methods (WHPO 91-1). Copies can be obtained by contacting either the WHPO in Woods Hole or the WHP SAC in Hamburg.

Procedures for unit conversions for all standard WOCE parameters are given in WHPO 91-1.

TABLE 2.5: WHP one-time survey standards for water samples

These data quality goals are regarded as attainable in low-gradient oceanic domains. They represent an ideal that can be achieved by appropriate methodologies such as those specified in the WHP Operations and Methods manual (WHPO 91-1). Standards for repeat hydrography sections are discussed in Chapter 2.

T: High resolution deep-sea reversing thermometers (DSRTs) are available and with careful calibration and reading may be capable of 0.004–0.005 °C accuracy and 0.002 °C precision. Digital DSRTs do not require long soaking times and, potentially, can serve as a means for calibration and performance checks. Their development, and in particular their long-term stability, will be closely monitored. Carefully documented and monitored use of multiple CTD sensors have the potential to eliminate the standard use of DSRTs.

P: accuracy 3 decibar (dbar) with careful laboratory calibration of the CTD; precision 0.5 dbar, dependent on processing.

S: 0.002 accuracy is possible with Autosal™ salinometers and concomitant attention to methodology, e.g., monitoring Standard Sea Water. Accuracy with respect to one particular batch of Standard Sea Water can be achieved at 0.001 PSS-78. Autosal™ precision is better than 0.001 PSS-78, but great care and experience are needed to achieve these limits on a routine basis as required for WOCE. For example, laboratories with air temperature stability of ±1°C are necessary for optimum Autosal performance.[1]

O_2: reproducibility[†]<1%; precision 0.1%. Some laboratories presently achieve 0.5% accuracy[†], which is recommended for WOCE measurements.[2]

NO_3: approximately 1% reproducibility[†] and 0.2% precision (this standard is probably appropriate to WHP).

PO_4: approximately 1–2% reproducibility[†] and 0.4% precision.

SiO_2: approximately 1–3% reproducibility[†] and 0.2% precision.[3]

^3H: reproducibility[†] 1%; precision 0.5% with a detection limit of 0.05 tritium unit (TU) in the upper ocean of the northern hemisphere and 0.005 TU elsewhere.

δ^3He: reproducibility[†]/precision 1.5 per mille in isotopic ratio; absolute total He of 0.5% with less stringent requirements for use as a tracer (e.g., He plume near East Pacific Rise).

CFCs: approximately 1–2% reproducibility[†] and 1% precision, blanks at 0.005 pmol/kg with best technique.

$\Delta^{14}C$: reproducibility[†] and precision 2 to 4 per mille via beta-counting on 200-liter samples; 5–10 per mille with Accelerator Mass Spectrometer (AMS) on 500 ml samples.

^{85}Kr: detection limit of 1% of surface concentration; precision of 4% decreasing to 25% for samples near the detection limit.

^{39}Ar: minimum detectable amount about 5% of surface value; precision of 5% of surface value.

^{228}Ra: 5% accuracy and precision.

$\delta^{18}O$: may be used in high latitudes; these should be measured with a reproducibility[†] of 0.02 per mille.

Notes:

† Where no absolute standards are available for a measurement then the obtainable limits for the measurement are taken to mean the reproducibility presently obtainable in the better laboratories.

1 Keeping constant temperature in the room where salinities are determined greatly increases their quality. Also, room temperature during the salinity measurement should be noted for later interpretation, if queries occur. The frequent use of IAPSO Standard Seawater is endorsed. To avoid the changes that occur in Standard Seawater, the use of the most recent batches is recommended. The ampoules should also be used in an interleaving fashion as a consistency check within a batch and between batches.

2 Improvements due to new techniques make such accuracy possible. Further development of these techniques and subsequent adoption is strongly recommended.

3 Strong opinion exists that with some methodologies laboratory temperature fluctuations cause significant errors, because 1°C laboratory fluctuation yields approximately 1% change in SiO_2.

TABLE 2.6: WHP one-time survey standards for CTD measurements

These data quality goals are regarded as attainable in low-gradient oceanic domains. They represent an ideal that can be achieved by appropriate methodologies such as those specified in the WHP Operations and Methods manual (WHPO 91-1). Standards for repeat hydrography sections are discussed in Chapter 2.

T: accuracy of 0.002°C; precision 0.0005°C (ITS_{90}).

S: accuracy of 0.002 PSS-78, depending on frequency and technique of calibration; precision 0.001 PSS-78, depending on processing techniques.[1]

P: accuracy 3 decibar (dbar) with careful laboratory calibration; precision 0.5 dbar, dependent on processing.[2]

O_2: reproducibility[†] 1%; same for precision.[3]

Notes:

† If no absolute standards are available for a measurement then accuracy should be taken to mean the reproducibility presently obtainable in the better laboratories.

1 Although conductivity is measured, data analyses require it to be expressed as salinity. Conversion and calibration techniques from conductivity to salinity should be stated.

2 Difficulties in CTD salinity data processing occasionally attributed to conductivity sensor problems or shortcomings in processing may actually be due to difficulties in accounting for pressure sensor limitations.

3 Existing polarographic sensors have been found to meet these requirements in low latitudes but better sensors need to be developed, particularly for use in high latitudes.