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SRL COMMUNICATION

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Guidelines for establishing a cytometry laboratory

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Abstract

The purpose of this document is to provide guidance for establishing and maintaining growth and development of flow cytometry shared resource laboratories. While the best practices offered in this manuscript are not intended to be universal or exhaustive, they do outline key goals that should be prioritized to achieve operational excellence and meet the needs of the scientific community. Additionally, this document provides information on available technologies and software relevant to shared resource laboratories. This manuscript builds on the work of Barsky et al. 2016 published in *Cytometry Part A* and incorporates recent advancements in cytometric technology. A flow cytometer is a specialized piece of technology that require special care and consideration in its housing and operations. As with any scientific equipment, a thorough evaluation of the location, space requirements, auxiliary resources, and support is crucial for successful operation. This comprehensive resource has been written by past and present members of the International Society for Advancement of Cytometry (ISAC) Shared Resource Laboratory (SRL) Emerging Leaders Program https://isac-net.org/general/custom.asp?page=SRL-Emerging-Leaders with extensive expertise in managing flow cytometry SRLs from around the world in different settings including academia and industry. It is intended to assist in establishing a new flow cytometry SRL, re-purposing an existing space into such a facility, or adding a flow cytometer to an individual lab in academia or industry. This resource reviews the available cytometry technologies, the operational requirements, and best practices in SRL staffing and management.

1 | GLOSSARY OF TERMS USED IN THIS RESOURCE

To aid comprehension for those new to the field, we have provided a list of specific terms used to describe the different types of commonly used cytometers, as well as a glossary of frequently used cytometric terms and a detailed list of commercially available cytometers. Shapiro's "Practical Flow Cytometry" book is a valuable resource, with dedicated chapters on the different components and measurements made on a cytometer [2]. A more recent reference is "Flow Cytometry Today" volume by Claudio Ortolani [3]. Additionally, Table 1 provides further definitions.

1.1 | Cytometry

The term cytometry refers to any method of measuring the properties of single cells. In this article, we are focusing on "high-throughput" cytometry where the sample is passed through an interrogation integration point instead of looking at a static sample as in microscopy. Depending on the way the data are generated or the type of data produced, we refer to this technique as flow cytometry, image cytometry, or mass cytometry.

1.1.1 | Analyzer

A flow cytometry analyzer is a device that is used for analysis of particles, usually cells, using one or more light sources to take both physical and chemical measurements of each cell. After data generation, the particles are usually discarded.

1.1.2 | Cell sorter

Cell sorters were one of the earliest cytometers designed [4]. They use the same principles of particle analysis as analyzers, but apply forces, typically electrostatic, to separate particles of interest based on their physical and chemical characteristics. With the advent of image-enabled cell sorting, particles can now also be isolated based on spatial and morphological traits. This allows viable cells to be used for various downstream assays. Cell sorters are commonly referred to

TABLE 1 A list of definition commonly used in cytometry many of which are referred to in this paper.

Term	Definition
ADC	Analog to digital converter; a system that converts an analog signal into a digital signal.
Aerosol	A suspension of small solid or liquid particles in a gas or air.
AMC	Annual Maintenance Contract, an agreement that the vendor signs with the customer for service and maintenance of instruments purchased by the customer.
Analyzer	A flow cytometry analyzer, is a piece of equipment that is used for analysis of particles (usually cells) using multiple light sources (usually lasers), taking physical (scattering of laser light) and chemical measurements (emitted fluorescence) with data being generated and the particles passing into the waste of the machine.
Avalanche Photodiode	A highly sensitive semiconductor photodiode detector that exploits the photoelectric effect to convert light into electricity.
Band pass filter	A specially coated piece of optical glass designed to allow only a specific range of light through while destroying the rest. These filters are labeled as center wavelength/band width. For example, a 525/50 bandpass filter would allow wavelengths from 500 to 550 nm to pass through and eliminate those above or below that range
BSL1/CL1	Biosafety level 1 or containment level 1; applies to settings in which work is done with low-risk microbes that pose little to no threat of infection in healthy adults.
Business continuity plan	The creation of a system of prevention and recovery from potential threats. This plan is in place to protect assets and personnel in case of emergency.
Cell sorter	Uses the same principles as an analyzer but the populations of interest are then separated out, usually using electrostatic forces. This allows viable cells to be used for further studies such as in vivo experiments, grown in tissue culture or used for genomic studies.
Cell sorter, cuvette based	The laser light interrogates the cells within a cuvette of the sorter before the stream of liquid exits the nozzle. These sorters are highly sensitive as there is limited loss of emitted photons but they are relatively slow.
Cell sorter, in-air	These sorters use high powered lasers to overcome photon loss as the lasers interrogate the cells within a stream of fluid. This sorter type is often called a high-speed cell sorter as they can sort more cells per second compared to cuvette-based sorters
Coincidence	When two particles pass in front of the laser at the same time so their signals cannot be separated
Colinear	When two lasers share the same path and fluorescence is collected in the same pinhole. In a colinear system, emitted fluorescence cannot be attributed to a specific excitation wavelength so some dyes cannot be used simultaneously
Conventional Flow cytometry	In a conventional flow cytometer, each fluorochrome is excited by an optimal laser line and its peak emission is collected with a narrow optical filter called a bandpass filter. With conventional flow cytometry multiple fluorochromes with the same excitation but differing emissions can be used together if their peak emissions aren't the same; each fluorochrome is detected in an individual channel.
Cost recovery	A business model where the fees leveraged are designed to offset costs rather than generate profit.
Cytometer	Any device used for measuring properties of cells which may include size, scatter, and fluorescence.
Dichroic mirror	A specially coated piece of optical glass designed to allow only certain wavelengths of light pass through while reflecting the rest.
Drop delay	The predicted time for a cell to travel from the analysis point of the sorter to being the last attached drop. This tells the sorter when to charge the stream to result in an appropriate charge in a given drop with it breaks off.
FACS	Fluorescence-activated cell sorting.
.FCS	Flow cytometry standard; data file standard for the reading and writing of data from flow cytometry experiments.
Fixation	Method to inactivate and preserve cells in a given state. Common fixation methods include formaldehyde or alcohol.
Fluorophore/fluorochrome	A molecule that can be excited by light and emits light of a different wavelength as it returns to its ground state.
Flow cell	Fluidic device that brings sheath and sample together for hydrodynamic focusing. Cuvette-based instruments have the interrogation point within the same part.
Flow cytometer	An instrument used for measuring cells or other particles as they move through a fluidic system. Measures both fluorescence and some light scatter properties.
FTE	Full-time employee.

(Continues)

TABLE 1 (Continued)

Term	Definition
H&S COSHH	Health and safety, Control of Substances Hazardous to Health.
High-throughput minimal volume screening cytometer	These instruments use automated equipment to rapidly test thousands to millions of samples for biological activity at the model organism, cellular, pathway, or molecular level.
I4S	Instruments for Science, a special task force under the ISAC which promotes and supports transfer of old and new flow cytometers to labs where resources are limited.
Image cytometry	A technique that combines the power of imaging analysis and the advantage of standard flow cytometry.
ISAC	International Society for Advancement of Cytometry.
LED	Light emitting diode.
Linear amplifier	An electronic circuit whose output is proportional to its input.
Logarithmic amplifier	Gives an output voltage which is proportional to the logarithm of applied input voltage.
Long pass filter	A filter designed to transmit wavelengths greater than the cut-off wavelength of the filter.
Mass cytometry/CyTOF	An analysis technique using mass spectrometry to detect heavy-metal-labeled antibodies on cells that have been focused and atomized one at a time.
Mass spectrometry	Analytical technique that determines mass to charge ratio of analytes or analyte fragments. May also be coupled with chromatography columns to enhance separation of complex mixtures. Often uses special isotopes as mass labels.
Microfluidic system	Devices that move or analyze the tiny amount of liquid, smaller than a droplet.
Photodiode	Is a semiconductor device with a P-N junction that converts photons (or light) into electrical current. The P layer has an abundance of holes (positive), and the N layer has an abundance of electrons (negative).
Photomultiplier tube	High gain, low-noise devices capable of detecting photons, converting them to electrons, and amplifying the signal.
Preventative maintenance	Regular and routine maintenance of equipment to keep instruments operating according to manufacturer specification and minimize unexpected equipment failure.
Quality Assurance	Any systematic process of determining whether a product or service meets specified requirements.
Quality Control/QC	A process through which a business seeks to ensure that product quality is maintained or improved.
Refurbished flow cytometer	Second-hand, restored usable flow cytometers that are fully functional after repair and service.
Risk assessment	A term used to describe the overall process or method by which potentially harmful hazards or risks are identified, evaluated, and eliminated or mitigated.
Shared resource lab/core facility	A laboratory which houses and maintains specialized equipment and expertise in a specific technology or technique.
Sheath fluid	A fluid in a flow cytometer that transports the samples through the instrument.
Short pass filter	A filter designed to transmit wavelengths shorter than the cut-off wavelength of the filter.
Solid state laser	A laser that uses a gain medium that is a solid, rather than a liquid as in dye lasers or a gas as in gas lasers.
SOP	Standard operating procedure. A written set of instructions for performing regular tasks such as maintenance, start up, or billing.
Spatially separated	In opposition of colinear. Each laser beam has a unique path and pinhole. Allows for separation of fluorochromes that have different excitations but similar emissions.
Spectral/full spectrum cytometry	A combination of hardware and software designed to use data from all fluorescent channels to deconvolute overlapping dyes using a process called spectral unmixing.
Tunable laser	A laser whose wavelength of operation can be altered in a controlled manner.

as FACS (Fluorescence Activated Cell Sorting) instruments, which is a trademark registered by Becton Dickinson (BD).

1.1.3 | "Conventional" flow cytometry

In the field of cytometry, the term "conventional" is used to describe the original flow cytometry technique that was first introduced with the launch of the FACS machine [5, 6] in 1975. Since then, the components of flow cytometers have remained relatively similar. Typically, a light source is used to excite fluorophores on or within single particles, resulting in the emission of photons at a longer wavelength. The photons are then collected to measure the relative fluorescence of the cell. Fluorochromes are chosen based on the laser line availability to ensure sufficient excitation, and their peak emissions are collected with narrow optical filters. With conventional flow cytometry, each fluorochrome corresponds to a single detector in the optical array, and multiple fluorochromes with similar excitation curves but

differing wavelength of peak emission can be used together if their peak emissions can be distinguished by bandpass optical filters. Most cytometers use multiple lasers, allowing dozens of fluorochromes to be potentially used in a single experiment. However, cross-laser excitation/emission contributes to the spectral spillover.

1.1.4 | Full spectrum (spectral) flow cytometry

An emerging technology in the field of cytometry that has gained popularity in recent years. In spectral cytometry, when a fluorochrome is excited across multiple laser lines, the emitted fluorescence is recorded across the entire spectrum. [7] This allows for the use of "conventionally" similar dyes, such as GFP and FITC, in the same experiment, as long as they have unique spectral signatures that can be distinguished [8]. Spectral flow cytometry relies on spectral unmixing algorithms to deconvolute the full spectrum data.

1.1.5 | Imaging flow cytometry

In addition to capturing analytical measurements and possibly sorting the particles, imaging cytometers also take an image of the particles as they pass through the flow cell [9]. Imaging cytometers give quantitative information as in a conventional cytometer with the addition of spatial and morphological insights into each cell (or particle). Image cytometers have some limitations including a reduced number of fluorescent parameters that can be acquired, for example the Cytek Amnis Imagestream MkII has the greatest capabilities with 12 parameters being acquired (2 Brightfield, 1 Side-Scatter and 9 fluorescence parameters). They also have a reduced speed in acquiring data compared to conventional cytometers but are faster than a fixed field of view microscope.

1.1.6 | Mass cytometry

Mass Cytometers collect signal from cells labeled with reagents conjugated to isotopically pure metals using mass spectrometry-based detection, allowing for resolution of over 50 targets per cell [10, 11], but presents a trade-off that involves the destruction of cells to allow signal detection. As cells are atomized and ionized by argon plasma to detect the metal tags, cell sorting becomes impossible. Mass cytometry systems have lower throughput than conventional cytometers, detecting a maximum of 500 events per second. Despite this limitation, mass cytometry has the advantage of not relying on fluorescence detection, making autofluorescence of samples or reagents a non-issue. The precise per-mass detection of metal isotopes also renders spectral unmixing and compensation generally unnecessary. However, inevitable isotope impurity of some reagents sometimes creates artifacts in mass cytometry data similar to effects of omitting compensation in fluorescence cytometry.

2 | INITIAL CONDISERATION REGARDING THE CYTOMETRY SRL SETUP

2.1 | Does your institution need a cytometer and/or a cytometry SRL?

Before an institution commits to the acquisition of new equipment and establishment of the SRL, they must evaluate what this decision entails. Cytometers are expensive pieces of scientific equipment and require regular maintenance to operate at their best, including a yearly maintenance and service contract from the manufacturer. Not every laboratory has the resources, in terms of both personnel and funding, to maintain and service a cytometer, particularly a high-maintenance cell sorter. Given their prevalence in clinical, biotech and academic research, it is possible that another SRL in the area has a suitable cytometer that could be utilized. It may be more cost-effective to use this SRL, if possible, rather than investing in and maintaining the institution's own equipment. In addition to saving space and equipment costs, this also frees up staff time that would be spent maintaining an underused instrument.

Using a cytometer on a nearly-daily basis is ideal for optimal performance, especially for sorters. This ensures that the fluidics systems are functioning properly and reduces downtime and problems with the instrument. In addition to the benefits of utilizing another SRL's equipment, their expertise can also contribute to maintaining the quality and efficiency of experiments run on those instruments. Additionally, many funding bodies expect efficiencies in equipment and will not fund a piece of equipment if an identical one is situated nearby that has unallocated capacity.

2.2 | Blue sky thinking: Designing the ideal cytometry lab

When it comes to setting up a cytometry SRL, the ideal scenario would be to have unlimited resources to design the lab from scratch. However, many cytometry core managers must work with existing infrastructure and make the most of what is available. It is still possible to envision an optimal cytometry SRL, complete with allocated funding for construction, laboratory supplies, and state-of-the-art cytometers, and implement the elements of this solution into the current framework of operation.

2.3 | Determining the ideal setting for the flow cytometer equipment within an institution

Whether one is a newcomer to cytometry or part of an established SRL seeking to acquire new instrumentation, the physical space available is a critical consideration. When selecting a location for a flow cytometer, it is imperative to consider not only the physical space it will occupy, but also its integration within your institution. This

encompasses accessibility, authorized users, and the sustainable financial backing of its operations. The financial and technical support that sustains the instrument is a crucial determining factor in its location and accessibility.

2.3.1 | In primary research labs

Across the range of possibilities, the ultimate "private use" solution is to place the instrument directly in the user's laboratory. These instruments may be purchased and maintained entirely by a single investigator and reserved for usage only by members of their lab or collaborators. When it comes to cutting-edge technologies, this is the best location for these instruments as often an experienced researcher will take charge of the instrument. This individual is likely to have devoted years to developing cytometry within the laboratory and is undoubtedly the individual most qualified to operate and maintain an innovative, possibly prototypical, piece of equipment. However, for more mainstream pieces of technology, such as standard analytical cytometers, isolation can present challenges, with maintenance, service, and contracts usually being cheaper and easier for greater numbers of instruments housed together. One approach to circumvent some of these issues is for an established SRL to offer investigators the chance to host cytometers in their labs, with the SRL providing maintenance and servicing for the instrument while the investigator trades instrument space for more local access to instrumentation used heavily in their research.

2.3.2 | Shared equipment space

In some cases, establishing a cytometry-only shared resource may not be feasible for smaller institutions due to a lack of users. However, these institutions may already have shared equipment spaces, such as those operated by a single investigator, department, or the institution itself. These spaces typically contain low-maintenance equipment like centrifuges and PCR machines, which can provide an ideal location for a user-friendly cytometer with minimal maintenance. It is important to carefully consider financial and technical support before purchasing the instrument, but the advantage of this option is that much of the auxiliary equipment for cytometry, such as centrifuges, may already be in place. Shared equipment spaces may also be a good fit for SRLs with plenty of users and staff, but only one or two instruments. This option may also work well for SRLs with only one or two instruments, or for small biotech companies that lack the resources or space for a dedicated cytometry lab.

2.3.3 | Shared resource laboratory

For large numbers of instruments or highly specialized and demanding instruments, placing the cytometer(s) in a Shared Resource Laboratory is likely the best option. As described by Moore & Roederer in 2009 [12], a "Shared Resource Laboratory (SRL) is a "resource that provides highly skilled technology scientists and advanced instrumentation to enhance the scope and quality of biomedical research.…The role of these laboratories has moved beyond the simple provision of technical services to making complex experiments possible by providing scientific and technological support for implementing advanced high-dimensional approaches in experimentation and by creating a mechanism for acquisition of new methodologies." When situating a cytometer in an SRL, it is not only the physical space and instrument requirements that requires consideration, but also the availability or procurement of highly-skilled staff as well as resources needed to fund the provision of technical services. As discussed in Moore et al, although funding is needed to establish an SRL, the investment will yield an asset to an institution both scientifically and economically.

3 | SRL INSTRUMENTATION

The selection of instrumentation for the new SRL is crucial in determining physical space requirements, staffing, and operational needs. With a variety of commercially available flow cytometers each having their unique strengths and limitations, it is important to consider multiple stakeholders when making a decision—customers, scientific leaders, funding bodies, and SRL staff—while balancing their competing requirements. This section will provide guidance on how to choose an instrument by effectively engaging with future users, highlighting potential pitfalls, and revealing hidden hurdles that may arise during the selection process.

3.1 | Choosing flow cytometers

The primary responsibility of the SRL is to offer a relevant and useful service to its customers and research partners. Effective communication is key to achieve this goal. It is essential to discuss all available options with customers and clearly explain the benefits and drawbacks of each piece of equipment. To have an effective conversation, one must understand the current state of the cytometry market. A list of most commonly used cytometric analyzers can be found in Table 2 and a list of cytometric sorters in Table 3.

3.1.1 | Assessing demand

To understand the requirements of the SRL's future users, it is important to engage with them. Successful grant applications require a clear justification of need, positive statements, and firm commitments from users. The SRL team can achieve this by getting familiar with prior research finding of the prospective users to assess how the cytometry facility could help them fill gaps in their existing research pipelines and expand their research program. Surveys can be helpful to quantify potential users and their needs. However, true needs should be distinguished from aspirational ones. New technologies are exciting, but it

TABLE 2 table showing the cytometric analyzers available on the market.

Name	Vendor	Type	Detector	Excitation source
Accuri C6 Plus	Becton Dickinson	Traditional	PMT	Laser
AQUIOS CL	Beckman Coulter	Traditional	PMT (FSC/SSC PD)+impedance	Laser
Attune	ThermoFisher	Traditional	PMT (FSC PD)	Laser
Attune CytPix	ThermoFisher	Imaging/traditional	PMT (FSC PD)+CCD brightfield	Laser
Aurora	Cytek Biosciences	Full spectrum	APD (FSC PD)	Laser
Amnis CellStream	Cytek Biosciences	Traditional	CCD	Laser
CyFlow CUBE	Sysmex	Traditional	PMT	Laser
CyFlow Space	Sysmex	Traditional	PMT	Laser
CytoFLEX	Beckman Coulter	Traditional	APD (FSC PD)	Laser
FACSCalibur	Becton Dickinson	Traditional	PMT	Laser
FACSCanto	Becton Dickinson	Traditional	PMT (FSC PD)	Laser
FACSCelesta	Becton Dickinson	Traditional	PMT (FSC PD)	Laser
FACSLyric	Becton Dickinson	Traditional	PMT (FSC PD)	Laser
FACSymphony A*	Becton Dickinson	Traditional	PMT	Laser
FlowSight	Luminex	Imaging	CCD	Laser
Galios	Beckman Coulter	Traditional	PMT	Laser
Guava	Cytek Biosciences	Traditional	PMT	Laser
Helios	Standard BioTools	Mass	TOF	Argon plasma
ID7000	Sony	Full spectrum	PMT	Laser
ImageStream MKII	Cytek Biosciences	Imaging	CCD camera	LED+Lasers
iQue	Sartorius	Traditional	PMT	Laser
LSRII	Becton Dickinson	Traditional	PMT	Laser
LSRFortessa	Becton Dickinson	Traditional	PMT (FSC PD)	Laser
LSRFortessa X-20	Becton Dickinson	Traditional	PMT	Laser
MACSQuant	Miltenyi	Traditional	PMT	Laser
Navios	Beckman Coulter	Traditional	PMT	Laser
Northern Lights	Cytek Biosciences	Full spectrum	APD (FSC PD)	Laser
NovoCyte	Agilent	Traditional	SiPM	Laser
S1000EON	Stratedigm	Traditional	PMT	Laser
SA3800	Sony	Full spectrum	PMT Array	Laser
SP6800	Sony	Full spectrum	PMT Array	Laser
XT	Standard BioTools	Mass	TOF	Argon plasma
ZE5	Bio-Rad	Traditional	PMT	Laser

is crucial to point out the advantages and possible pitfalls of equipment, particularly new technologies. It is unlikely that a user has used a new technology before, so it is essential to assess the true likelihood of them using it and remember that new projects do not always get funding. It is also important to establish from current users what an acceptable wait for an analyser or sorter session would be as this will help to denote whether additional cytometers with the same capabilities are needed. Outside of the institution housing with the SRL, other core facility leaders can provide informative opinions on the current and future state of the field. It is also worth talking to local sales representatives from cytometry companies to learn any new instruments or upgrades that are going to be released in the near future, as this information might impact what equipment is appropriate to purchase.

3.2 | Cytometer acquisition

3.2.1 | Evaluation

Acquiring instruments is a crucial task for a core facility that requires careful consideration and evaluation. The evaluation of an instrument should be divided into four assessments: functionality, usability, cost, and longevity.

Functionality

The functionality of an instrument is critical, and it should perform as advertised with relevant capabilities for the end users. The best way to assess this is by arranging an onsite demo of a potential new

TABLE 3 Table of currently available cell sorters on the market.

Name	Vendor	Type	Detector	Sorting method
Astrios	Beckman Coulter	Traditional	PMT (FSC PMT in EQ and EQs)	Sense in air
Aurora CS	Cytek	Full Spectrum	APD	Cuvette
Bigfoot	ThermoFisher	Full Spectrum	PMT	Sense in air
Biosorter	Union Biometrica	Traditional	PMT	Sense in air
COPAS	Union Biometrica	Traditional	PMT	Cuvette
CytoFLEX SRT	Beckman Coulter	Traditional	APD	Cuvette
FACSAria	Becton Dickinson	Traditional	PMT	Cuvette
FACSAria Fusion	Becton Dickinson	Traditional	PMT	Cuvette
FACSAria II	Becton Dickinson	Traditional	PMT	Cuvette
FACSAria III	Becton Dickinson	Traditional	PMT	Cuvette
FACSMelody	Becton Dickinson	Traditional	PMT	Cuvette
FACSymphony S6	Becton Dickinson	Traditional with spectral option	PMT	Cuvette
Influx	Becton Dickinson	Traditional	PMT	Sense in air
Jazz	Becton Dickinson	Traditional	PMT	Sense in air
MA900	Sony	Traditional	PMT	Microfluidic chip
MACSQuant Tyto	Miltenyi	Traditional	PMT	Chip
On-Chip Sort	On-Chip	Traditional	PMT	Microfluidic chip
S3e	Bio-Rad	Traditional	PMT	Sense in air
SH800	Sony	Traditional	PMT	Microfluidic chip
WOLF Cell Sorter	NanoCellect	Traditional	PMT (FL and BSC detectors), PD (FSC)	Microfluidic chip
XDP	Beckman Coulter	Traditional	PMT	Sense in air
FACSDiscover S8	Beckton Dickinson	Image-enabled & Full Spectrum	PMT & APD	Cuvette

instrument. This provides an opportunity for prospective users to run their samples on the instrument and provide feedback. It is essential to ensure that the current instrument meets the users' requirements and not to rely on promises of future upgrades that may take months or years to materialize.

In clinical settings, there are stricter requirements than in research laboratories, and a clinically rated cytometer is often necessary, along with the associated third-party certifications. In this article, we do not describe the needs and considerations of a clinical cytometry laboratory setup.

Usability

Usability refers to the instrument's day-to-day requirements, including startup and shutdown procedures, necessary consumables and auxiliary equipment. Staff involvement in instrument operation is a critical consideration when integrating the instrument into the facility's operational plan. Instruments that are operated by staff require little to no user training, while those that are operated independently or semi-independently by users offer greater flexibility in terms of staff coverage.

It is also important to evaluate any potential hazards introduced by the new instrument, such as biological, environmental, or IT risks, such as high level of noise produced by the instrument or outdated software that impose data safety concerns. These hazards may require mitigation measures and even facility renovations before instrument installation.

Costs

The cost of maintaining and repairing an instrument is a significant long-term expenditure, so it is important to consider service and consumables costs when negotiating the purchase price. Typically, service costs can make up around 20% of the instrument cost per year. Major equipment manufacturers offer various packages of maintenance services, with a balance between the cost, the services covered, and the estimated response time. Often, the manufacturer offers a bundle discount on service contracts for multiple instruments, creating an incentive to purchase several instruments from the same company, and additional discounts for multi-year contracts. The latter can be an attractive option for instrumentation funded through NIH instrumentation grants that require a five-year institutional commitment to back the service contract with the institution's internal funds.

If there is no service contract, some SRLs set aside a monthly budget to cover eventual repairs for certain instruments. In these cases, it is crucial to estimate the cost of components and anticipate their failure. Additionally, without a service plan, repair priority may be lacking, which may result in increased instrument downtime.

Longevity

The operational life of a flow cytometer instrument depends on several factors. Typically, institutions set a standard lifespan of 10–15 years for an instrument, which is usually sufficient to recover costs or justify expenses. However, factors like manufactured obsolescence,

changes in legal requirements, scientific advancements, or component critical failure can reduce its lifespan. To mitigate such risks, when purchasing a flow cytometer, try to negotiate a service lifetime guarantee from the supplier if possible. It is also essential to consider the long-term scientific vision of your institution and be cautious about investing in expensive instruments if there may be a change in leadership.

There are resources available to assist with evaluating instruments [13], such as lists of items to test during a demo and other purchasing considerations.

3.3 | Auxiliary and supplemental equipment

In addition to cytometers, several pieces of equipment are necessary or recommended for the smooth operation of a cytometry SRL. Table 4 categorizes this equipment as either ancillary equipment that is essential for all cytometry SRLs or equipment that is recommended, especially for sample preparation and processing.

3.4 | IT and software

Although a cytometer can be used for post-acquisition data analysis, this is not recommended as it limits other users from collecting data and the built-in software often has limited analysis capabilities. Therefore, post-acquisition software should be factored into the purchase of a cytometer and may be included in a package deal with the cytometer manufacturer since many of them also provide post-acquisition software. Any cytometer, especially a high-dimensional and imaging instruments, generates large files that necessitate storage considerations. It is advisable to factor in data storage into grant applications to ensure that data files are stored for the length of time required for the grant study.

TABLE 4 A list of auxiliary equipment needed for a cytometry laboratory.

Equipment	Rationale	Details	Enhancements
Light microscope	A light microscope is needed to visually assess samples. At a minimum, a hemocytometer and Trypan blue must be available for viability staining and cell counting.	An inverted microscope with phase contrast, a range of objectives, and FITC and Texas-Red filter sets will allow analysis of most samples in plates and on slides.	Automatic cell counters with live/dead discrimination ability are particularly relevant for cell sorting applications or large volume SRLs.
Pipettes	SRL users will often require sample manipulation during their cytometer usage, necessitating pipettes and tips.	At a minimum, a complete set ranging from 1ul to 1000 µl should be provided by the SRL as well as sterile pipette tips.	For SRLs where a large amount of sample preparation is performed, a multichannel pipette and all necessary consumables may be provided by the SRL.
Vortexes	Thorough cell resuspension through vortexing is essential to quality sample acquisition.	Each cytometer should have an orbital vortex in close proximity, preferably one per cytometer.	Vortex allows thorough mixing of samples and reagents
Centrifuges	All SRLs will find utility in having a centrifuge.	Access to at least one hanging bucket rotor, tabletop centrifuge is desirable. Smaller centrifuges may also be useful for cytometry-associated protocols such as antibody labeling.	If extensive sample handling occurs in the SRL, then a variety of tube and plate adaptors for the rotor will be required for centrifuges and temperature control ability is highly desirable.
Sonicating water bath	Nozzle-based sorters and mass cytometry systems will need a sonicating water bath for small part cleaning.	Ensure that the size of the water bath can accommodate the parts to be cleaned.	A heated water bath is beneficial for cleaning, but not required.
Temperature controlled storage	Daily QC beads and other dyes/reagents will require storage at 2–8°C.	A refrigerator is absolutely required.	For long-term storage of stock reagents, a − 20° or −80°C freezer is desirable.
Cell culture equipment	A humidified, CO_2 controlled incubator will allow for culture of samples. A class II biological safety cabinet will facilitate safe, sterile sample preparation.	SRLs should consult with their local biosafety office for regulations and requirements.	Some SRLs may provide sample preparation services and require liquid nitrogen storage for cryopreserved cell suspensions.
Deionized water and autoclaves	The ability to deionize water and sterilize buffers is a common feature of many SRLs.	Access to deionized water and autoclave systems will likely be required. These systems, if shared, should be nearby and highly accessible.	SRLs using large volumes of buffers may desire to prepare these in-house, and will require bench space, analytical balances, stir plates, and associated supplies.

3.4.1 | Data management and data safety

Proper data management and safety are crucial in any research setting, including cytometry SRLs. Data generated during cytometric acquisition should be backed up promptly, and ideally, the backup should be transferred to a remote location to prevent data loss due to computer failure, lab emergencies, or malicious attacks. Most institutions offer solutions for data preservation, and the backup process can be automated using a combination of manufacturer software features and backup software [14] Unless necessary for specific research purposes, user data should never contain patient-identifying information. All SRL computers should have up-to-date security features, and outdated equipment that requires unsupported software and operating systems should be safeguarded with custom firewall setup to prevent external attacks. Due to security risks involved, it is highly inadvisable to connect USB portable devices to systems running an outdated operation system that have reached the end of support and therefore are not secured against malicious software threats.

3.4.2 | Data analysis software

There are a variety of options available for cytometry data analysis, ranging from open-source free platforms to paid packages (see Table 5). These solutions are typically comparable with different instruments and vary in their features, especially when it comes to complex workflows and data display options. When selecting an analysis platform, it is important to consider the projected use cases and applications, the available software features, the number of licenses required, license pricing (standalone or tiered), and the platform's accessibility of the platform (local or cloud-based).

By providing cytometry data analysis resources, SRLs can reduce the barrier of entry for investigators looking to incorporate cytometry into their research. Engaging multiple investigators allows SRLs to purchase software licenses in bulk, reducing the per-license cost. SRLs should aim to have at least one version of a group license for analysis software available to their user base. Access to additional licenses of the software designed by the instrument manufacturer to be used

TABLE 5 Table showing a list of flow cytometry software available.

Name	Vendor/language	Cloud computing	Biaxial gating available	HD analysis tools	Open source	Operating system(s)
Astrolabe	Astrolabe diagnostics	Y	N	Y	N	MAC and Windows
BD FACSDiva	BD Biosciences	N	Y	N	N	Windows
CellCapTure	Stratedigm	N	Y	N	N	Windows
Cytobank	Beckman Coulter	Y	Y	Y	N	MAC and Windows
CytoExploreR	R	N	Y	Y	Y	MAC and Windows
CytoPy	Python	N	N	Y	Y	MAC and Windows
CytoSwarm	Applied Cytometry	Y	Y	Y	N	Windows
FCS Express	DeNovo Software	N	Y	Y	N	MAC and Windows
flowCore	R	N	Y	N	Y	MAC and Windows
FlowJo*	BD Biosciences	N	Y	Y	N	MAC and Windows
FlowLogic	Inivai Technologies	N	Y	Y	N	MAC and Windows
ForeCyt	Satorius	N	Y	N	N	Windows
GemStone	Verity Software House	N	N	Y	N	MAC and Windows
Infinicyt	Cytognos	N	Y	N	N	Windows
Kaluza	Beckman Coulter	N	Y	N	N	MAC and Windows
Modfit LT	Verity Software House	N	Y	N	N	MAC and Windows
NovoExpress	Agilent	N	Y	N	N	MAC and Windows
OMIQ	OMIQ, Inc.	Y	Y	Y	N	MAC and Windows
Red Matter	Red Matter	Y	Y	N	N	MAC and Windows
SpectRe	R	N	Y	Y	Y	MAC and Windows
SpectroFlo	Cytek Biosciences	N	Y	N	N	Windows
Tercen	Tercen Data Analytics Ltd	Y	Y	Y	N	MAC and Windows
VenturiOne	Applied Cytometry	N	Y	Y	N	MAC and Windows
Weasel	Frank Battye	N	Y	N	N	MAC and Windows
WinList	Verity Software House	N	Y	Y	N	Windows

*Free in Africa.

along with instrument use on a standalone workstation not connected to the instrument may come at an extra cost but provides users the flexibility of offline data analysis and experimental setup. It also allows for user training without reducing instrument availability. It is becoming increasingly common to allocate larger projects to cloud computing. SRLs should consider utilizing institutional resources for these tasks or acquiring cytometry-specific cloud-based solutions with integrated analysis pipelines.

3.5 | Essential cytometry resources for an SRL

There is a plethora of cytometry resources available online, which can be overwhelming. Table 6 provides a list of resources that be particularly useful for the SRL staff to expand their cytometry knowledge, connect with others in the field and find support.

3.6 | Second-hand instruments

Purchasing a used or refurbished cytometer can be a cost-effective option, but it is important to consider certain factors before making a purchase. For example, an ex-demo instrument from a company may have been frequently moved and prematurely aged. Some cytometer manufacturers offer trade-in deals on new instruments, which can make older models available at a reduced cost. However, it is also critical to ensure that the instrument still has a significant amount of service time before becoming obsolete and to request a warranty with the purchase. Buying a cytometer from another company or SRL is also a viable option, but the costs of moving and evaluating the instrument before placing it on a service contract must be taken into account. Renting a cytometer through a third-party contracted by the manufacturer may be a good option for short-term needs, but over time can result in being more expensive than buying one outright.

3.6.1 | Refurbished or second-hand instrumentation acquisition

In SRLs where funding is limited, purchasing second-hand refurbished instruments can be an effective way to equip the facility on a budget, and may also pave the way for future acquisition of new equipment. Refurbished instruments can be obtained from established cytometer manufacturers and third-party suppliers who may specialize in cytometry or provide a wide variety of instrumentation. However, one must consider the potential drawbacks of purchasing used equipment, particularly the lack of manufacturer's warranty and the potential challenges in obtaining after-sale service and maintenance. Different institutions may have varying attitudes towards the acquisition of used equipment; some may support this approach while others may discourage or prohibit it.

While purchasing a refurbished cytometer from reputable companies with experience in flow cytometry can be a viable option for SRLs with limited funding, it is important to carefully consider certain factors. These companies are often small and may have limited geographical coverage, which can lead to lead times for field support, especially in remote locations. These companies may go through changes and transition, which highlights the importance of having a maintenance and service plan in place in case the vendor disappears.

Another option for refurbished equipment is larger companies that provide a wide range of laboratory instrumentation including flow cytometers. However, these companies may have less in-house expertise in flow cytometry specifically. Some of these companies operate only in certain regions, such as the US and Europe, and may be better equipped to provide regulatory compliance than smaller companies.

A third option for purchasing refurbished instrumentation is to look to the cytometer manufacturers themselves. These companies often offer demonstration instruments and recently trade-ins models at significant discount. While more expensive than a used instrument from a third-party supplier, the purchasing lab is likely to receive the full warranty and service support of a new instrument purchase, making it a more secure investment. Additionally, some companies offer yearly contracts through Memorandums of Understanding (MoUs) signed by the institutions and the companies. If a core facility is shopping for a cytometer with limited funds, then it is worth notifying the manufacturers that a refurbished instrument purchase is an option. Local distributors for larger instrument manufacturers may also be a source of used equipment.

Although there are reputable used equipment companies that offer excellent service, some vendors may not provide adequate support or have the intention to do so. There is a real risk of purchasing a poorly functioning instrument with little or no support. Therefore, it is essential to conduct thorough research of the vendor and speak with the previous customers to assess the level of service and support provided. Even honest vendors with good intentions can still fail to meet their obligations. It is important to ensure that the company you are considering can legally do business in your country. Some companies may have to do business through a local distributor, and it is crucial to verify that the local distributor can meet the SRL's needs.

3.6.2 | Refurbished instrumentation for the SRLs in resource limited settings

For the resource limited laboratories, it is possible to explore the possibility of instrument donations from other institutions. This option may not come with formal support, but the recipient may have some knowledge about the instrument history, and the gifting institution may offer valuable technical assistance. One formal initiative in this regard is the National Cancer Institute's (NCI) cytometer donation program, spearheaded by Dr. William G. Telford (USA). This program, which started in 2002, has utilized the National Institutes of Health's Property Donation to Foreign Institutions program to gift refurbished flow cytometers to almost 30 countries across the globe. In addition to shipping and installing the equipment, this program provides long-term training and technical support, and attempts to provide service

TABLE 6 List of useful resources for cytometry laboratories.

Introductory resources	
Shapiro's practical cytometry	The classic reference book for anyone interested in understanding flow cytometry technology or interested in developing expertise in flow cytometry applications.
Open flow initiative	Open Flow is an open access Flow Cytometry education resource. The Open Flow initiative is collaboration between the Francis Crick Institute (London, England), Memorial Sloan Kettering Cancer Center (NY, NY, USA) and the Whitehead Institute for Biomedical Research (Cambridge, MA, USA).
Vendor websites	Vendor websites are a good resource of technical information. They also usually offer protocols, technical support and educational resources. Key vendors include BD Bioscences, Cytek Bioscences, Beckman Coulter, ThermoFisher, Abcam, and Biolegend.
Reference Journals	
Cytometry Part A	*Cytometry Part A* is a journal of quantitative single-cell analysis and features original research reports and reviews of innovative scientific studies employing quantitative single-cell measurement, separation, manipulation and modeling techniques. A special peer-reviewed Cytometry Part A publication type are OMIPs, and they aim to report on newly designed and optimized multicolor panels for flow cytometry, fluorescence microscopy, image cytometry and other polychromatic fluorescence-based methods.
Current Protocols in Cytometry	Comprehensive collection of cytometry protocols focused on the detection and analysis of various cellular populations including instrumentation, data processing and analysis and cell and molecular imaging.
Cytometry community	
International Society of Advancement of Cytometry (ISAC) and Cytometry University (CYTO U)	ISAC is the Global Community of Cytometry Professionals. ISAC membership provides a huge range of education and networking opportunities. ISAC organizes an annual conference (CYTO). CYTO U is an online portal for on-demand, peer-reviewed cytometry education from ISAC. This site offers multi-module courses, recorded sessions from the CYTO conference, and webinar series.
Professional societies	Become a member of the local, regional, national, or international cytometry-focused professional societies for learning, mentorship and networking opportunities will be available there. Such organizations include: ACS (Australasia Cytometry Society) LatinFlow (Iberoamerican Cytometry Society) *flowcytometry*UK Additionally, these societies for core facility professionals have a cytometry track and/or offer cytometry content to the members: CTLS (Core Technologies for life sciences) ABRF (Association of Biomolecular Resource Facilities)
The Cytometry Society-INDIA (TCS, INDIA)	This was constituted in 2005 and since then has been organizing several workshops (both with and without ISAC association, and courses and has provided several cytometry resource materials in India. https://tcs.res.in/about-society.php
Purdue Cytometry List	Purdue PUCL Cytometry discussion list was established in 1989. The list is open to all scientists to ask questions or debate topics of concern in the cytometry field.
CyTOForum	http://cytoforum.stanford.edu Established in 2014, an open online forum for all mass cytometry.
Cytometry databases	
FlowRepository website	FlowRepository is a database of flow cytometry experiments where you can query and download data collected and annotated according to the MIFlowCyt standard (ref). It is primarily used as a data deposition place for experimental findings published in peer-reviewed journals.
RRID	Research Resource Identifiers (#RRID) are ID numbers assigned to help researchers cite key resources (antibodies, model organisms and software projects) in the biomedical literature to improve transparency of research methods.
Other resources	
FluoroFinder	FluoroFinder's website has collected the resources needed to get started with flow cytometry experimental designs offering tools such as comprehensive antibody search combined with interactive instrument configurations or spectra viewer.

to the instruments in the recipient laboratories. The NCI has also collaborated with non-profit organizations such as Seeding Labs, which offers substantial equipment awards to laboratories all over the world and supports existing instrumentation by providing service support and upgrades in-place equipment. These programs offer a great opportunity to acquire a flow cytometer and contribute to the betterment of global research.

The NCI program is just one example of programs that offer new and used cytometry equipment to laboratories in need. Another option is to approach a research collaborator to inquire about retired instrumentation, which can lead to mutually beneficial arrangements and facilitate collaborative research. However, such lab-to-lab donations can be challenging due to institutional regulations and difficulties with international equipment transportation. To further promote these initiatives, ISAC has established the Instruments for Science (I4S) Task Force. This group encourages and supports the transfer of both new and used cytometry instruments to laboratories with limited resources and serves as information resource with experienced membership to assist in building such programs. In most cases, these donations are part of a scientific collaborations between laboratories and nations, providing access to collaborators. Although major national and philanthropic funding mechanisms support much of this work, the efforts of ISAC scientists in volunteering their time are a crucial component. The NCI and I4S programs work closely with ISAC education programs, including the ISAC Education Committee and the ISAC Live Education Delivery group, to endure that cytometer recipients are placed on the training schedules for these committees. Many instrumentation recipients are now ISAC and committee members, strengthening their scientific skills and providing local support to other scientists in their regions.

4 | THE PHYSICAL AND FUNCTIONAL REQUIREMENTS FOR A FLOW CYTOMETRY LAB

4.1 | Location

SRLs can come in various shapes and sizes, with some centralized in a single space while others scattered throughout a campus. There are advantages to having a centralized core facility, such as an ease of operation and maintenance, shared supplies and storage spaces, and a single address to navigate users. However, on larger campuses, it may be inconvenient for users to travel long distances to reach the facility, especially when dealing with live samples where timing is crucial. In such cases having several smaller core facilities might be more advantageous, albeit more challenging to manage. It is important to ensure that the facility is easily accessible for all users, with careful planning of the routes from parking areas to elevators, corridors, and entrance doors. This will ensure that all users can arrive at the core safely and with ease. If the SRL is not on the ground floor, the weight limit of the laboratory floor should also be taken into consideration as some sorters can weigh more than 750 kg.

4.2 | How much space is enough?

The allocation of space is a crucial factor to consider when designing a scientific laboratory, including SRLs. While there is no standard formula to calculate the necessary space, guidelines are available to assist in the process. Alongside physical dimensions, instrument vendors typically provide the minimum working space required for the instrument, which takes into account the appropriate clearance necessary for operation, maintenance, and service. In addition to instrument space, the operators also require space to work. It is important to consider all activities that will take place within the lab, including training, which requires sufficient space for both the trainer and trainees, without interfering with neighboring workstations. If the lab is also used for teaching purposes, adequate space should be allocated for multiple students to use each cytometer. It is recommended to include extra space whenever possible, and an open floor plan with moveable laboratory furniture can allow for easy rearrangement of equipment, enabling the acquisition of new instruments without requiring disruptive renovations. Figures 1 and 2 show examples of SRLs of differing sizes. Figure 1 shows the layout of a large SRL with 5 sorters and 7 analyzers including space for staff of 6. Figure 2 shows the layout of a small SRL which houses 2 analyzers.

4.2.1 | Entryways into the laboratory

In addition to the laboratory space itself, the entryway into the SRL must be carefully planned. The doorway should comply with laboratory design requirements and be at least 36 inches wide to accommodate equipment movement. SRLs can opt for automatic sliding or traditional manual doors, but they should have a self-closing door mechanism to ensure the facility is always secured. Access restriction points such as badge readers should be installed near the entrance door, especially for the Level 2 (Biosafety Level 2 or Containment Level 2) and higher spaces. Glass panels or viewing ports should be included to in the SRL doors to allow for observation, which is particularly important when the lab is at full capacity.

If the SRL is not on the ground floor, then the size and weight limits of the elevator that will be used to transport cytometers and other equipment should be considered. Lab planners must review the pathway for equipment to the SRL door exit, the turns along the hallway, the capacity of service elevator, and the building exit or loading bays.

4.2.2 | Working with hazards

SRLs can vary in size ranging from single rooms to suites of rooms. Depending on the type of the samples being worked with, an anteroom with negative pressure may be necessary to isolate potential hazards from the rest of the building. For labs working with samples above BSL-1 or local equivalent, this is especially important. It is also recommended to separate analytical cytometers from sorting

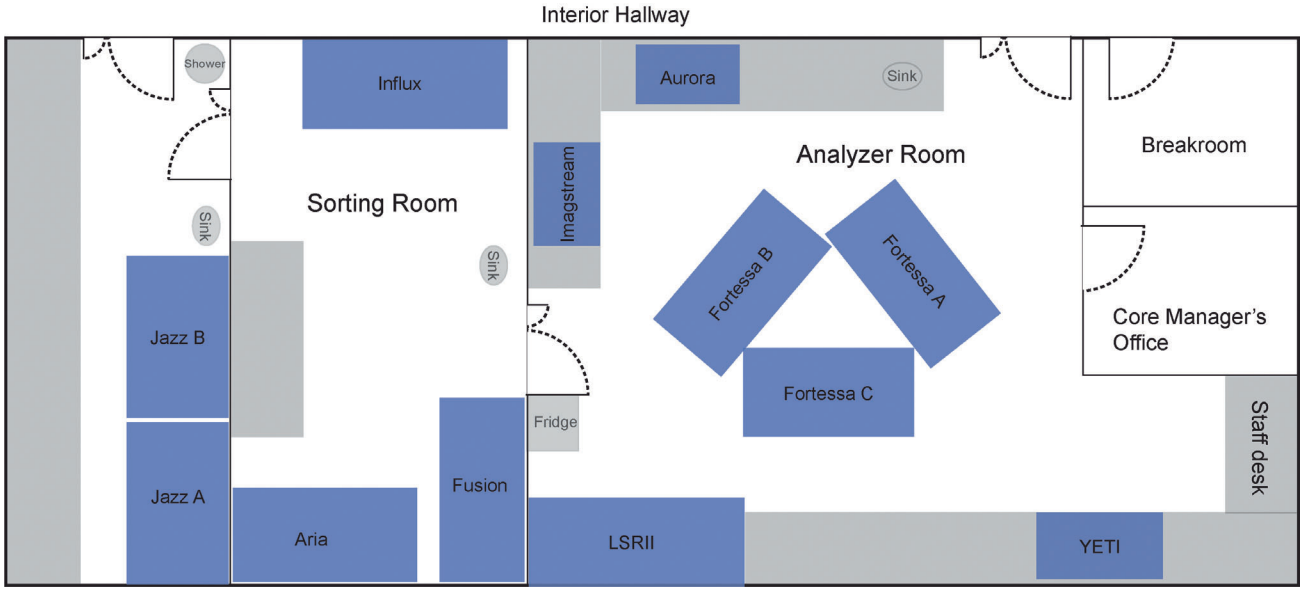

FIGURE 1 The arrangement of cytometers within a large Cytometry SRL which houses six cell sorters and seven analyzers. [Color figure can be viewed at wileyonlinelibrary.com]

instruments in the design of a flow cytometry suite so that analyzers can still operate even when a hazardous sort is occurring. Anterooms serve as a layer of access control to instrumentation space and a location for ancillary equipment, storage, and safety items. Flammable reagents requiring their own safety cabinets can be stored in the anteroom as well.

4.3 | Storage

Storage is an essential aspect of any flow cytometry SRL, as it needs to accommodate a wide range of scientific reagents and chemicals. While local requirements should always be followed regarding where and how certain chemicals can be stored, some general guidelines can be helpful. It is crucial that adequate shelving or cabinet space is provided for room temperature chemicals so that incompatible chemicals are not stored near each other. Additionally, at each instrument, a designated area should be allocated for sheath cubes with a storage base, as required.

Flammable Chemicals, such as various alcohols, are commonly used in the most flow cytometry SRLs. If the SRL regularly uses such chemicals, it is recommended to have a cabinet for flammables of appropriate size. This not only improves access but also ensures safe storage of these chemicals.

Temperature-controlled storage space is also essential in proximity to the instruments for refrigerators and freezers, which are for a variety of refrigerated and frozen reagents and supplies.

The lab space must be equipped with sinks, eyewashes, and possibly a safety shower. Locations for items needed for decontaminating and cleaning spills should also be planned, as well as receptacles

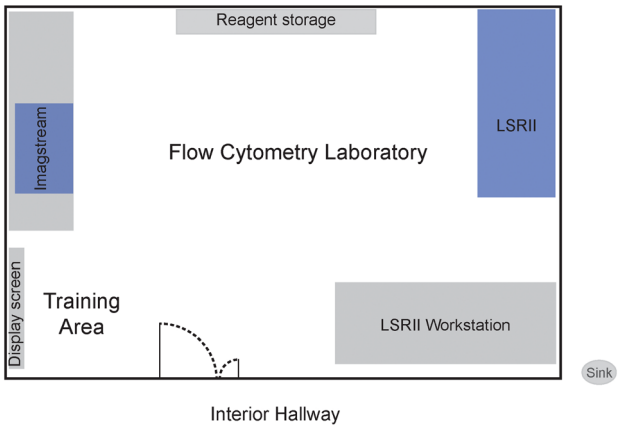

FIGURE 2 The arrangement of cytometers within a smaller Cytometry SRL which houses two analyzers. [Color figure can be viewed at wileyonlinelibrary.com]

appropriate for regular, biohazard, chemical and chemical waste streams.

4.4 | Tissue culture

To better serve customers from outside the immediate building, it is recommended that the SRL provides resources for sample preparation. These resources may include tissue dissociators, sonicators, water baths, incubators, biosafety cabinets, filters, and centrifuges. Keeping these ancillary resources within the SRL or in proximity ensures that the viability of samples can be best preserved and minimizes the movement of biohazardous samples through open space.

4.5 | Workstation setup

Laboratory benches are typically available in standardized dimensions. However, users often spend several hours with their numerous samples to be analyzed. Therefore, it is important to consider ergonomics as well as health and safety guidelines when setting up benches to hold cytometers as well as auxiliary equipment such as computers, vortexes, and sample holders. In addition, the monitor, keyboard, and mouse must be set up at the correct height with ample space for samples on the benchtop. A comfortable chair made of spill-proof material with stop wheels should also be provided.

4.6 | Non-laboratory spaces

A research laboratory that conducts flow cytometry experiments requires additional spaces beyond the laboratory itself. These spaces may include:

Kitchen or Lunchrooms: to ensure that the SRL staff have access to food and drinks throughout the day, a dedicated space for the storage of food and drink containers is necessary. It is best to locate this space immediately outside of the laboratory area for easy access during busy days.

Offline analysis workstations: Many SRLs provide workstations for analyzing flow cytometry data. These workstations need to be connected to the network for data transfer and may be located within or outside of the lab. It is preferable to place these workstations in area close to the staff administrative space for easy assistance as needed.

Meeting and teaching rooms: SRLs require access to spaces to meet with researchers and teach. Ideally, these rooms should be located nearby and able to accommodate larger groups for classes. Each room should be equipped with a whiteboard or other surface for communication and an A/V setup.

Offices: SRL management have administrative tasks that require dedicated office space. The decision to have a dedicated space per employee or shared desks is determined by available space and individual operation styles.

4.7 | Health and safety

4.7.1 | Biosafety

Biosafety comprises two main components: Risk assessment (RA) and Risk management, with the goal of reducing laboratory acquired infections and exposure to hazardous materials and preventing illness and injury in the workplace. Flow cytometry SRLs should have an active biosafety program that includes both their customers and/or users and their institutional biosafety personnel. The institutional Environmental Health and Safety officer should be fully informed of the protocols used in the facility and ready to screen user protocols as the new facility is being established.

Given that flow cytometers can generate aerosols, biosafety practices should include methods for reducing aerosol exposure. The mitigation measures needed are determined through the RA and depend on the samples and organisms to be handled, as well as the specific procedures to be performed with those samples. The components of a typical SRL biosafety program have been detailed in several publications; please see Table 7 for a list of program components and their corresponding References [15–19].

4.7.2 | Laser safety

Nearly all cytometers contain one or more lasers and although the majority of them are contained within the cytometer and therefore defined as Class 1 lasers during normal operation, education about lasers is needed for those operating a cytometer. With some Cytometers containing a Class 3b laser (MoFlo Legacy and Influx sorters) care needs to be taken when aligning those laser beams especially the invisible UV laser. Laser safety glasses with the appropriate filters for the laser line being worked on should be worn. All members of staff and users should be excluded from the room whilst laser alignment is being carried out. A sign should be placed on doors and if possible an exclusion tape added to the doorway (it is not advisable to lock the room). These procedures should also be carried out when an engineer is carrying out a laser alignment on a Class I or II cytometer as laser beams become exposed. This document from University of Cambridge is an excellent resource for explaining the types of lasers, the potential dangers of lasers and how to work safely with laser. [20]

4.8 | Waste management

When setting up operations for an SRL, it is important to assess the risk associated with materials that will be allowed in the facility and to establish proper disposal method. Institutional flow cytometry SRLs often allow materials that require BSL-2+ safety precautions, and it is crucial to properly manage the disposal of biohazardous waste, as well as the buffers and reagents used in preparing and running samples, which may also present hazard risks. One effective strategy for managing hazards is to eliminate them altogether. For instance, most SRLs prohibit the use of radioactive samples and chemical materials that can be substituted with safer materials or techniques (e.g., not sorting cell population into TRIzol collection buffer). Whenever possible, elimination or replacement should be considered.

When hazardous waste cannot be eliminated, SRLs must seek guidance with their local Environmental Health and Safety (EH&S) Department on allowable agents, decontamination and sterilization policies, and restrictions on using municipal solid waste and wastewater systems. The most relevant hazardous waste to flow cytometry SRLs is biohazardous waste. Although institutions may have varying

TABLE 7 List of biosafety program components and topics with the corresponding references where detailed descriptions are available.

Biosafety topic	Relevant references
ISAC Biosafety guidelines	Schmid et al. 1997, *Cytometry Part A* 28: 99–117 Schmid et al. 2007, *Cytometry Part A* 71: 414–437 Holmes et al. 2014, *Cytometry Part A* 85: 434–453
Guidelines for high-risk samples	Cossarizza et al. 2020, *Cytometry Part A* 97: 668–673 Reifel et al. 2020, *Cytometry Part A* 97: 674–680
Guidelines for analyzers	Aspland et al. 2021. *Cytometry Part A* 99:81–89
Risk assessment	Schmid 2012, *Methods* 57 (3): 392–397 Holmes et al. 2014, *Cytometry Part A* 85:434–453 Barsky et al. 2016, *Cytometry Part A* 89: 1017–1030
Determination of risk group or hazard group	Schmid 2012, *Methods* 57 (3): 392–397 Holmes et al. 2014, *Cytometry Part A* 85: 434–453 Pathogen Safety Data Sheets (Public Health Agency of Canada)
Determination of biosafety level or containment level	Schmid 2012, *Methods* 57 (3): 392–397 Holmes et al. 2014, *Cytometry Part A* 85: 434–453
Aerosol containment system/aerosol containment testing	Perfetto et al 2003, *Cytometry Part A* 52: 122–130 Holmes 2011, *Cytometry Part A* 79: 1000–1008 Holmes et al. 2014, *Cytometry Part A* 85: 434–453 Perfetto et al. 2019, *Cytometry Part A* 95: 173–182 Reifel et al. 2020, *Cytometry Part A* 97: 674–680 CYTO U video by Evan Jellison and Geoff Lyon
Standard operating procedures	Schmid 2012, *Methods* 57 (3): 392–397 Holmes et al. 2014, *Cytometry Part A* 85: 434–453 Barsky et al. 2016, *Cytometry Part A* 89: 1017–1030
Biosafety Questionnaire	Schmid et al., 2003, *Cytometry Part A* 56: 113–119
Regulatory requirements	Holmes et al. 2014, *Cytometry Part A* 85: 434–453
Training and education	Barsky et al. 2016, *Cytometry Part A* 89: 1017–1030
Appropriate disinfectants for various agents	EPA List N

policies, the most commonly used method for disinfecting liquid waste is to use a 10% final concentration of household bleach for 30 min before pouring it down the drain with plenty of flowing water. It is important to note that diluted bleach loses its disinfecting ability quickly and should be prepared daily from the concentrated stock.

Solid biohazardous waste is routinely collected in red biohazard bags placed in hard-sided containers with lids, and then autoclaved to sanitize it. Some institutions have a solid biohazardous waste stream in place, which reduces the responsibility of SRLs to sterilize solid waste. It is crucial that SRLs and EH&S departments are aware of any local regulations that restrict the types of waste that can enter municipal waste streams.

4.9 | Environmental control

4.9.1 | Ventilation

Ventilation rates are typically based on guidelines, and in the US, the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) recommends minimum outdoor air ventilation rates for general laboratory ventilation. The ANSI/ASHRAE Standard 62.1 and 62.2 specify how much outdoor air should be brought into a room every hour, based on factors such as occupancy and room size. The air vents in the room should also be considered, especially for instruments such as Image Stream and sorters, which require adequate air movement. These instruments should not be placed under or near air vents, and a minimum clearance distance behind the instrument should be maintained to ensure proper ventilation.

4.9.2 | Vibration

When selecting a location for the core, it is important to consider the physical requirements of the instruments. For instance, many imaging cytometers are sensitive to vibrations, which can be caused by nearby vibration-forming machinery (such as large autoclaves, compressors, generators, large air treatment units etc.) or heavy vehicles passing by. These vibration sources may also contribute to environmental noise that might disturb the users and staff. To mitigate these issues, it is essential to

measure the levels of vibration and noise at potential locations and consider adjustments such as isolating the floor and walls or using special tables for sensitive instruments. By taking these factors into account, the core can be situated in a suitable location that minimizes any potential interference with instrument performance and user experience.

4.9.3 | Noise

The flow cytometry SRL can be affected by various noise sources such as air compressors, chillers, compressed gasses, and fume hoods. Occupational Safety and Health Administration (OSHA) sets the permissible exposure limit for noise exposure as time-weighted average of 90 dBA over an 8-h shift. However, according to the OHSA, noise levels of 55 dBA and higher are already considered prohibitive for intelligible speech comprehension in the lab and therefore must be addressed when possible. To minimize compressor noise, the use of in-house compressed air should be preferred, while storing chillers and compressed gasses in spaces not utilized for daily instrument operation at the core. However, mitigation of other sources of noise may require more creative methods. Regular measurement of noise levels is crucial to assess the sound hazard and determine any changes in noise levels over time.

4.9.4 | Temperature

Temperature control is crucial in research laboratories that use flow cytometry, as temperature stability is important for instrument performance. When selecting a location for the laboratory, it is important to consider the operating temperature range specified by the instrument vendors, as well as the maximum rate of temperature change per hour. Additionally, the laboratory's sun exposure should be considered, and a laboratory with a north exposure may be preferred for positioning cell sorters.

4.9.5 | Humidity

Humidity levels should also be controlled, especially for the imaging cytometers, as high humidity can negatively impact the optical system. Vendors can provide the allowable room relative humidity, and dehumidifiers can be used if needed to maintain the specified ranges.

4.9.6 | In-house compressed air

Most flow cytometers require compressed air, which can be supplied either through an onboard air compressor or in-house air compressor ("house air"). The latter is preferable when possible due to its lower noise levels. A backup compressor should be available in case of a failure of either the in-house or the onboard air compressor. It is important to plan ahead and determine the number and location of compressed air outlets in the lab for future instruments that may require external air.

The air supply should provide a pressure of approximately 4–7 bar and must be free of oil, dust, and other contaminants. A combination of particle filters (1 and 0.01 μm), a dryer, an activated charcoal filter, and a subsequent 0.01 μm particle filter should be used. These humidity traps should be regularly cleaned, and filters should be replaced as needed.

4.10 | Staying connected—electrical and IT

When setting up a flow cytometry SRL, it is important to ensure that the electrical and IT infrastructure meets the necessary requirements. Site preparation guides for electrical laboratory equipment will provide information about power requirements, including the need for high-amperage power outlets for most cytometers, and lower-amperage outlets for other equipment. Power outlets in different countries can have different voltages, and the amount of current that can be drawn from a given circuit can vary depending on the installation. To ensure that the SRL has the necessary power infrastructure, it is important to consult with a local electrician about current and future needs.

The number of outlets required in a flow cytometry laboratory will depend on the number of cytometers and ancillary equipment. In a survey among the ISAC SRL Emerging Leaders group, more than half of the respondents reported having at least six power outlets per sorting station, and at least four power outlets per analyzer station. This will ensure that there is enough electricity not just for the cytometers, but also for the other equipment that is necessary such as vortexes.

In addition to ensuring that the lab has the right number and type of power outlets, it is also important to consider emergency power or the use of an uninterruptible power supply (UPS). This will allow users to continue their experiments during a power outage, or at least to safely shut down and save their data. A majority of the SRL Emerging Leaders surveyed had their flow cytometers on emergency power backup. The use of a power conditioner can also help to prevent power surges or spikes, which can prolong the life of the instruments.

4.11 | Considerations and requirements for specialized cytometry instruments

4.11.1 | Automated cytometers

In recent years, advancements in cytometer technology have allowed for more lasers and detectors to be incorporated into instruments of a similar size to those of a decade ago. However, there are also smaller and more automated cytometers and cell sorters on the market that require less bench space, but often come with a fluidic cart which be situated under the bench.

4.11.2 | Robotics

For large-scale cytometry operations that rely on automated plate readers for high-throughput experiments, robotic systems are typically integrated with these machines. In addition to allocating space for the hotel to store plates, space must also be considered for the robotic arm to move between the hotel and the instrument.

4.11.3 | Mass cytometry

Special laboratory requirements must also be considered for mass cytometry (CyTOF), which combines single cell antibody labeling with mass spectrometry-based detection. The CyTOF system requires rear clearance for two exhaust vents and two dedicated electrical branch circuits, as well as a standard power supply for the computer. Additionally, the instrument requires a high purity argon gas supply and has a considerable weight of 400 kg, not including the weight of the computer workstation or gas canisters, which may be substantial in the case of liquid argon.

4.11.4 | Field or aquatic cytometry use

Flow cytometers are increasingly used in limnology and oceanography to examine particles in water, from microorganisms to sediment. Sometimes, these instruments are deployed in the field or on vessels to analyze the environment of interest. However, when working in the field, space and power can be limited, so careful consideration must be given to those factors. Field stations usually prefer instruments with a small footprint, if permitting based on their research needs. Most commercial instruments require a dry space and conditioned power to operate. To ensure proper operation, it is important to place all instrumentation in a dry space and connect it to an uninterrupted power supply with battery backup. In some cases, a power conditioner may also be necessary to protect against brownouts. When considering the use of a cell sorter at field stations, limited access to onboard in-house compressed air or vacuum supplies can be a challenge. In these situations, a portable air compressor and vacuum pump are necessary.

When working on ships or small coastal vessels, in-house air compressors are often not available, and in some cases compressed nitrogen gas can be used as an alternative. However, the inability to control environmental conditions poses significant challenges. Humidity and temperature stability can prevent or minimize operations, and weather conditions, particularly rough seas, can affect instrument performance. Given that deployments at sea can last 1–2 months, extensive knowledge of instrument operation and repair is critical. Additional training can be obtained from the instrument service provider for a fee. Besides the day-to-day supplies required for normal instrument operation, a set of spare parts to repair or replace sample, sheath or vacuum lines is necessary. A preventative maintenance kit and other parts or sensors that could be easily replaced are recommended. Before transporting or moving an instrument into the field or onto a vessel, it is vital to discuss emergency parts and transport recommendations with a qualified vendor representative.

5 | FACILITY OPERATIONS

When setting up a new SRL, it is essential to establish comprehensive policies for facility operation and usage. These policies will play a vital role in the success of the SRL. In this section, we will provide an overview of the crucial areas that define how an SRL operates in relation to its user base.

5.1 | Models of operation

When opening a flow cytometry resource to the public, one of the first decisions to be made is how open to make it. Most shared resources operate a hybrid model, where some processes are conducted by shared resource staff and some by users. The decision of the division of responsibilities depends largely on factors such as the trainability of users in instrument operation, complexity of instrument operation, availability of staff to conduct this training or operate these instruments, and infrastructure to monitor operations of the shared resource. Ultimately, the level of involvement and accessibility of the SRL is decided by the SRL Director and staff, keeping in mind the benefits for the SRL and the affiliated institutions. Providing SRL services to external users can generate additional income, but there are also financial and legal implications to these services. The parent institution may have protocols for such interactions, including separate rates for external users and contract requirements. Limitations may also exist on the services that external users can access. For example, it may be inadvisable or impossible to train external users in instrument operation due to institution access limitations or liability concerns.

5.2 | Financial sustainability

When establishing the SRL, it is crucial to have a clear understanding of how the facility will be funded and what the annual operating costs will entail [21–23]. These expenses may include salaries and benefits for employees, training and professional development for staff, overhead costs, consumable purchases, capital equipment investments, and equipment maintenance. The most commonly used methods to cover these expenses are institutional support, services fees charged to users, and grants awarded directly to the facility. To achieve a cost-neutral model, many SRLs use a combination of these funding approaches. The mechanisms used to offset the annual operating costs can significantly impact staffing levels, capital equipment investments, and whether instruments are fully covered under manufacturer service contracts or funded through allocated resources for annual preventative maintenance and repairs. For the SRL facilities in the

USA, an NIH guide (FAQ for Costing of NIH Funded Core Facilities) is a crucial resource to guide financial strategy and compliance with funding agency policies. [24]

5.3 | Staffing

When it comes to staffing a flow cytometry SRL, there are several important factors to consider. These include the core research mission, budget and funding structure, the number and type of instruments, service models, and available career paths for staff members. It is the staff who drive the research mission of the SRL and add value to the facility through their skills, expertise, and experience. Below, we dissect the main factors in the staffing process.

5.3.1 | Lab hierarchy

There is a wide range of staffing structures for SRLs, with positions varying from routine technicians to the highly specialized senior scientists, and from operations managers to scientific visionaries. The most senior position is typically a Scientific Director, who has significant impact and influence on the organizational and SRL development. [12] Working under the Director, there is often a managing or operational director who oversees the facility's day-to-day operation. This position requires a good understanding of the technology, excellent communication, mature management skills, and an understanding of the long-term vision for the SRL. This manager may oversee a team of junior staff, technicians, or technical specialists who are skilled in flow cytometry, instrument maintenance, and quality control. Candidates who are well-organized, attentive to detail, able to follow standard operating protocols (SOPs) and solve problems are preferred. Soft skills such as empathy, common sense, and ability to work as part of a diverse team are also important assets. Clear requirements and duties should be defined for all roles.

5.3.2 | Capacity

When determining staffing requirements for a flow cytometry SRL, several factors need to be considered, including the SRL service model, the type and number of instruments, facility hours, and financial situation. As discussed in Barsky et al., the number of staff needed typically increases with the number of instruments [1, 25]; one core staff member is usually responsible for 3 and 4 instruments in North America and about 6 instruments in Asia. More complex instruments such as cell sorters generally require increased SRL staff engagement. Facilities equipped with labor-intensive instrumentation would also require more staff, as self-operation by users would involve challenging and time-consuming training.

The SRL's sustainability is also an essential consideration, with a larger user base and diversified funding resources potentially allowing for increased self-sufficiency. It is helpful to benchmark the SRL performance and assess its capacity limits to determine target staffing levels, as outlined in FASEB's "Maximizing Shared Research Resources Part I" [26]. Ultimately, understanding the SRL's capacity and performance metrics will aid in defining and calculating staffing requirements.

5.3.3 | Retention and staff professional development

The staff of an SRL is crucial to its success, and therefore, it is important to establish a staffing structure and career development plan that attracts, motivates, and retains outstanding staff members. It is essential to consider the SRL sustainability and equity in terms of specialist experience, duties and responsibilities. To achieve that, target staffing levels and the ideal ratio of short-term vs long-term staff should be defined. Apart from providing adequate training for the staff to perform their jobs, it is critical to establish a clear career development path with defined goals, action plans, and regular assessment of objectives. These topics should be reviewed at least once a year, during annual performance evaluations. It is essential to gauge the interest level of staff and focus on goals, opportunities for development, salary increase, and promotions. Opportunities for continuing education, such as attending relevant conferences, and protected time for the SRL staff to engage with the field, can help develop expertise, identify emerging needs, and maintain the highest level of services for customers. A small yearly budget can fund these types of projects and keep staff engaged and informed of relevant technologies and research methods.

Additionally, staff should be encouraged to take the accreditation exam for the Specialist in Cytometry (SCYM) credential jointly offered by ISAC, ICCS (International Clinical Cytometry Society) and Board of Certification of the American Society of Clinical Pathologists (ASCP) [27]. SCYM certification demonstrates a high level of competence and expertise in the field of cytometry. This certification can be valuable for the SRL, enhancing the lab's credibility and reputation, and demonstrating to potential users and collaborators that the lab is committed to maintaining high standards of quality and expertise.

5.4 | User training

Flow cytometry is a complex scientific tool that necessitates a thorough comprehension of the technology to effectively plan and execute a successful experiment. It is not uncommon for situations to arise where the data do not match expectations. This could be due to various factors such as lack of thorough experimental design, substandard sample preparation, inadequate experimental controls, instrument malfunction, inappropriate instrument usage, or poor practices in data analysis. Gaining a deep understanding of root causes of such experimental failures can only be possible through experience augmented with a comprehensive training program. Investigators frequently utilize an SRL not just for instrument access but for the technical and scientific expertise of the facility staff. Therefore, it is

recommended to implement a mandatory training program that encompasses both theoretical and practical aspects to support research. Before commencing the training, it is advisable for designated SRL staff and investigators to discuss expectations and the trainee's needs [28].

5.4.1 | Theoretical knowledge

Despite the development or user-friendly flow cytometry instruments that are relatively easy for novices to operate, it is still essential for researchers to have a fundamental understanding of the technology to incorporate it effectively into their research. Theoretical introductory classes should cover relevant technologies, instrumentation, experimental and panel design, sample preparation and controls, data acquisition and quality control, the basics of data analysis, and biosafety considerations.

This theoretical review should be completed before hands-on training and may be repeated after independent use of instrumentation. The frequency of the theoretical training can be adapted to accommodate the needs of incoming trainees. In addition to the introductory course, the SRL should also offer specialized courses tailored to meet the unique needs of researchers at all levels, encompassing the workflow from experimental design to publication.

5.4.2 | Practical knowledge

Proper training for instrument operation is crucial to enable independent use of the equipment. Typically, training sessions are conducted with SRL staff and the trainee together at the instrument. The number of sessions required may vary depending on the trainee's prior experience and the complexity of the instrumentation and experiments. During the training session(s), the following subjects should be covered: instrument power, fluidics management, sample loading, basic troubleshooting, software operation, and data management. Additionally, any instrument-specific techniques should also be reviewed. A comprehensive practical training will also familiarize the user with the shared resource spaces, operating policies, staff and any auxiliary equipment or supplies available to users. To support hands-on training, it is useful to have a set of established protocols for instrument operation. ISAC has a repository of SOPs contributed by facilities worldwide. [29]

Users of the flow cytometry instrument should undergo an evaluation process to assess their proficiency in both theoretical concepts and practical aspects of the technology. In addition to familiarity with topics covered in the training, users should be required to demonstrate their ability to operate the instrument independently, including tasks such as instrument setup, sample loading, basic troubleshooting, software operation, and data management. This evaluation process may include a practical exam, where the user performs a flow cytometry experiment and demonstrates their ability to troubleshoot any issues that may arise. A "driver's test" pass/fail system can be utilized to grant clearance for accessing the instrumentation.

5.5 | Facility communications

Effective communications with users is crucial for SRLs to establish and maintain a positive relationship with their user base. Not only it helps repeat business, but also enhances the SRL's reputation as satisfied users are likely to refer new customers. The first step in building this rapport is to establish efficient and documented communication channels with users. These channels can be utilized to report instrument issues and relevant events within the core, such as staffing changes, price updates, and changes to policies and procedures. There are several communication methods available for SRL facilities:

Newsletters are an easy way to keep in touch with users and should include helpful information such as latest news about staff, publications, conferences, new equipment, and training programs. Newsletters can be sent out as electronic mail to the SRL's user base.

Emails can be used to rapidly distribute urgent information such as instrument downtime, changes to facility hours, or other urgent SRL news.

Workshops/Guest Speaker talks provide the SRL with the opportunity to meet users face-to-face and provide them with helpful information and skills. If SRL is not hosting an event, they can still communicate online opportunities for user enrichment.

Social Media platforms offer a fast way to communicate with the user base. This can be used to distribute urgent information, share relevant content or announce SRL achievements.

Websites serve as an official record and contact point for the SRL. The design and content of the website can vary based on the SRL's needs, ranging from in-depth to simple stubs. Fully utilized, websites can provide a public-facing compendium of information about the SRL, including contact and scheduling information, policies, training and instrument information, and other resources needed by users accessing the SRL.

5.6 | Institutional communications

Effective communication between an SRL and its users is crucial, but it is equally important for the SRL to be included in the communications from its parent institution. Failure to provide clear communication about planned or unplanned infrastructure shutdowns and upgrades, IT issues, water or air handling shutdowns, and other events can negatively impact SRL operation and user research projects. To prevent this, SRLs can forward announcements of these events to their user base, post signs, or update websites and social media. Users should also be informed about how

institution-wide policies may affect SRL operation, particularly when SRL policies are stricter than the institution-wide policies. During the initial stages of the COVID-19 pandemic, for example, institutions had to clarify or interpret policies and expected procedures for SRLs and their user base [30]. Therefore, SRLs should collaborate with the institution's governing bodies to ensure that all users receive the correct communications regarding issues affecting the SRL.

5.7 | SRL acknowledgement and recognition: Establishing a fair, transparent and enforceable policy

It is crucial that SRLs are not evaluated solely on their ability to recover costs, but also on their contribution to scientific outputs [31–33]. Some scientific outputs, such as author or co-authorships, grant awards, or patent applications, are easy to measure. Other contributions are more difficult to track. Contributions to user publications that fall below the level of authorship may be tracked through acknowledgements, but since acknowledgements are not standardized, automated tracking can be challenging. Still, since funding agencies often evaluate performance of the grant application by tracking publications that acknowledge the granting source, it is extremely important to secure the appropriate acknowledgements. For example, failure to receive acknowledgements for using the instrumentation purchased through NIH instrumentation grants may result in poor evaluation on subsequent grant applications from the same institution.

To track outputs that are linked to a given SRLs activities, it is essential to have a formal policy for acknowledging the role of the SRL. At a minimum, any presentation, paper, or poster should acknowledge the core facility, ideally using pre-set text that is trackable using an automated alert system. Research Resource Identifiers (RRIDs) are standardized SRL identification codes that link back to resource databases that can assist with these issues. Enforcing any acknowledgment policy can be challenging, as it requires institutional oversight to ensure that all manuscripts contain the appropriate statements and authors. Acknowledgement can be incentivized by reinforcing the need to demonstrate that SRL is contributing to outputs. Additionally, regularly searching the literature for outputs linked to a given SRL may enable the SRL to contact any groups who overlooked its contribution to their work and encourage acknowledgement in future. When possible, it is best to initiate discussions about acknowledgement and authorship early on in any project or new user relationship.

5.8 | Software solutions for facility management

A well-designed facility management software can optimize the operation of an SRL and enhance adherence to best practices. Though the process of selecting or building a facility management software can be overwhelming, the benefits of implementing it can make a significant difference in the long-term success of a facility. According to the survey conducted at ISAC 2019 CYTO conference workshop, the most important features of a facility management software are actual usage tracking, statistics and reporting, responsiveness of software developers, automatic user authentication, and email notification. Some of the suggested improvements for such software include mobile app features, billing/invoicing, and search tools.

When considering project management software, it is essential to look for features that allow tracking development and milestones and the ability to append different types of data formats. For staff management software, critical features may include flexibility, linking staff to instrumentation schedules, and tracking the personnel utilization. Table 8 presents a list of key features to consider when integrating facility management software, while Table 9 offers a comparative overview of the features found in popular facility management software solutions.

TABLE 8 Considerations to be made when deciding on laboratory management software.

Overall considerations	Cost
	User-friendly
	Calendar integration with third-party calendars
	Branding
	Mobile app
	Communication tools
	Responsiveness of tech support
	Various access rights levels (user vs administrator)
	Accessibility
	Adaptability
	Ease of use
Facility management	Instrument booking
	Usage tracking
	User training management
	Ordering facility services
	Price and subsidy rules
	Invoice generation
	Reporting statistics
	Publication tracking
Lab management	Inventory management
	Ordering consumables
	Data tracking
Project management	Sample processing management
	Track development/milestones
	Assign staff
	Append data
Staff management	Flexibility
	Link to instrumentation schedules
	Track utilization of personnel

Features	iLab	PPMS	Bookitlab	Infinity	Quartzy
Resource scheduling	Yes	Yes	Yes	Yes	Yes
Billing and invoicing	Yes	Yes	Yes	Yes	Yes
User management	Yes	Yes	Yes	Yes	Yes
Inventory management	Yes	Yes	Yes	Yes	Yes
Reporting and analytics	Yes	Yes	Yes	Yes	Yes
Equipment tracking	Yes	Yes	Yes	Yes	No
Instrument reservation	Yes	Yes	Yes	No	No
Electronic lab notebook	No	Yes	No	No	No

TABLE 9 Comparison of the features implemented in several popular facility management software solutions.

5.9 | Synergy—combining SRL technologies

Flow cytometry SRLs often collaborate not only with their users but also with other SRLs. For example, sorted cells from cell sorting services may be used in genomics or imaging SRLs. Additionally, some instruments may blur the line between flow cytometry and other technologies, requiring greater interaction. As SRLs may have more in common with each other than with standard research laboratories, they often have shared oversight or departmental management. Therefore, it is crucial to consider relationships between SRLs at your institution when setting up a new laboratory.

Establishing strong ties between cytometry SRLs and other SRLs such as imaging and genomics can be beneficial. Centralizing all the cores in one location can allow for better communication, cross-training of staff, and shared storage and administrative support. Increased communication between SRL staff members at all parts of a sample workflow can help inform users about improved preparations or other applications.

The organizational structure of the SRL should reflect the needs of the institution and users. A larger institution with a larger user base can support a broader range of more narrowly focused SRLs than a smaller institution. Conversely, the more focused on a specific technology, the more specialized the SRLs can be and the more streamlined their workflows are. However, in some cases, it may be beneficial to combine multiple SRLs into joint operations, or to integrate them substantially. Joint SRLs may need to manage both scheduling and project/request-based resources and establishing clear responsibilities and priorities among staff is essential for successful operations.

5.10 | Contingency planning

It is common for SRLs to experience downtime due to instrument maintenance, breakdowns, or staffing shortages. While service contracts can help with preventative maintenance and faster repair times, it is essential to have a contingency plan in place to minimize disruption of operations during outages. Consider establishing a relationship with a neighboring SRL to run samples while waiting for an engineer.

Another issue that may arise is capacity constraints on a cytometer. Accurate records of instrument usage should be kept to document that uses the instruments and for how long. This information is useful for procuring additional instruments and ensuring that the workload is distributed fairly. Additionally, scheduling regular maintenance for a cytometer is important. Approximately, 20% of the working day should be dedicated to essential cleaning and quality control at a frequency recommended by the manufacturer and based on usage.

5.10.1 | Repurposing surplus cytometers

Some companies specialize in selling old cytometers on behalf of an institution to minimize electronic waste. If they fail to find a buyer, the equipment components can be recycled. Another option is to repurpose a cytometer by donating it to a local school for use in science projects.

6 | CONCLUDING THOUGHTS

This document serves as a comprehensive guide for establishing and operating a flow cytometry shared resource lab. It is valuable not only for those starting a new SRL, but also for existing labs seeking to improve their operation procedures and instrumentation. A shared resource lab is a dynamic entity; comprising both instruments and the people, and it is important to establish infrastructure that can support growth and change over time. The goal of a shared resource lab is to better science and technology by supporting the research community, and the collaboration between researchers and industry. Together, we can achieve a symbiotic relationship that benefits everyone involved.

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