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Discussion of US EPA Drinking Water Guidance Manual Draft 2003

Introduction

- UV EPA Design Manual developed under direction of EPA's Office of Water and prepared by:
  - Malcom Pirnie, Inc.,
  - Carollo Engineers
  - The Cadmus Group Inc.,
  - Dr. Karl Linden & James P. Malley, Jr

History

- 1887: Germicidal Properties of Sunlight Discovered
- 1901: Development of Mercury Lamps
- 1906: Use of Quartz as Transmitting Material
- 1910: First Drinking Water Disinfection Application
- 1930: Fluorescent Lamp Developed
- 1955: Disinfect Municipal Drinking Water in Switzerland and Austria
- 1970's: DBP's Discovered. UV Popular in Hundreds of WTP's in Norway & the Netherlands
- 1996: Over 2000 European Drinking Water Systems Using UV Disinfection
- 1999: US EPA embraces use of UV in Drinking Water
- 2000: Group of Stake Holder (Regulatories, Consultants, UV Vendors) work on Draft Guidance Manual
- 2001: Release of 1st Draft Version of Guidance Manual, October 2001
- 2003: Release of Final Draft Version of Guidance Manual, June 2003

History

- Objective of US EPA Guidance Manual
  - Provide technical information relating to application of UV equipment for disinfection
  - Provide principals of UV disinfection
  - Establish guidance on Crypto and Giardia dose levels (Tier 1 and Tier 2 approach)
  - Establish recommended locations for UV equipment (post filtration, clear well, HSP)
  - Support of 2 EPA's upcoming drinking water regulations:
    - Long term 2 enhanced surface water treatment rule (LT2ESWTR)
    - Stage 2 disinfection byproduct rule (DBP Rule) (places more stringent limits on certain disinfection byproducts)

Purpose

- Audience and Objectives:
  - Provide utilities and design engineers with technical information and guidance on selection, design, operation of UV installations and UV related requirements for compliance with LT2ESWTR
  - Provide states with guidance and necessary tools to asses UV installations at the design, start-up, and routine operation phases
  - Provide manufacturers with testing and performance standards for UV components and systems for treating drinking water

Purpose

- Structure of Manual:
  - Key elements:
    - Summary of LT2ESWTR and Stage 2 DBPR
    - Summary of the Principals of UV Disinfection
    - Planning and Design Aspects of UV Disinfection
    - UV Reactor Validation
    - Start-up and Operation of UV Installations
    - Bench Scale and Pilot Scale Testing
    - UV Lamp Breakage
    - Additional Reference Material

US EPA

UV Disinfection Guidance Manual

(DRAFT - June 2003)

(FINAL - Due 2004)

~500 pages of Valuable Design Information!

www.epa.gov

Document IDs:

OW-2002-0039-0031

OW-2002-0039-0045

OW-2002-0039-0046

OW-2002-0039-0047

OW-2002-0039-0048

OW-2002-0039-0049

OW-2002-0039-0050

US EPA UV Manual

Country	Name	Character	UV Involvement	Comments
USA	LT2ESWTR	Surface Water Quality	No	Covers Parasites
USA	Stage 2 DBPR	Disinfection Standard	No	Covers Chlorine By-Products
USA	Ground Water Rule	Ground Water Quality	Yes	Covers UV and Viruses
USA	**EPA UVDGM**	**UV Standard**	**Yes**	**UV in Drinking Water**
USA	NWRI	UV Standard	Yes	UV in Reclaimed Waste Water
USA	NSF Standard 55	UV Standard	Yes	Point of Use

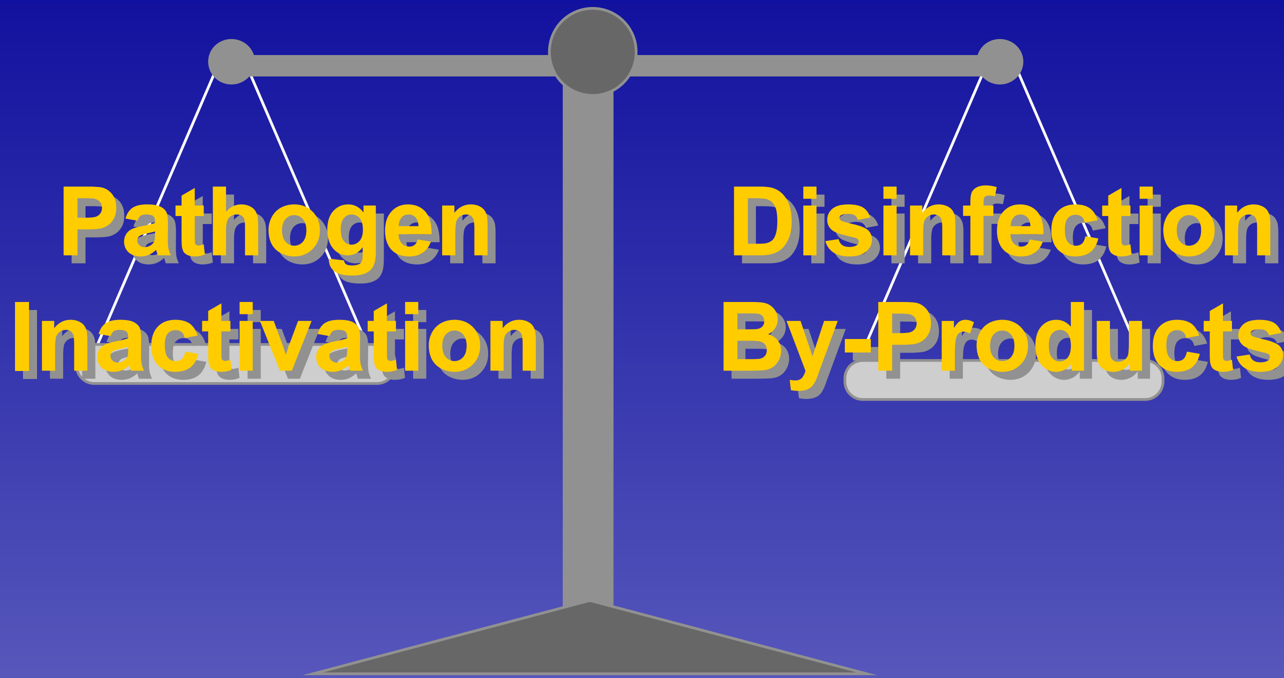
International Regulations, Standards and Directives involving UV

- Need to balance risks of disinfection of micro-organisms against formation to DBPs
- *Crypto's* known resistance to traditional chemicals ($HOCl^-$, ClO_2, O_3, etc.)
- Previous UV-*Crypto* work was misleading regarding the UV dose thought necessary for inactivation of microorganisms

Why UV Disinfection Now?

Must Balance Risks

Disinfection vs. Formation of DBPs



Chlorine/Chloramines ⟷ **THMs, HAAs**

Chlorine Dioxide ⟷ **THMs, HAAs, Chlorite**

Ozone ⟷ **Aldehydes, Bromate**

UV Radiation ⟷ **NONE**

Balance Risks

Crypto's Resistance to Chlorine Dioxide ClO_2 CT Values (mg-min/L) for *Cryptosporidium* Inactivation

Log Credit	**Water Temperature, °C**					
	1	**5**	**10**	**15**	**20**	**25**
0.5	305	214	138	89	58	38
1.0	610	429	277	179	116	75
1.5	915	643	415	268	174	113
2.0	1220	858	553	357	232	150
2.5	1525	1072	691	447	289	188
3.0	1830	1286	830	536	347	226

SOURCE: EPA Federal Register LT2ESWTR: Proposed Rule Aug. 11, 2003.

CT-Table

Crypto's Resistance to Ozone
O_3 CT Values (mg-min/L) for *Cryptosporidium* Inactivation

Log Credit	**Water Temperature, °C**					
	1	**5**	**10**	**15**	**20**	**25**
0.5	12	7.9	4.9	3.1	2.0	1.2
1.0	23	16	9.9	6.2	3.9	2.5
1.5	35	24	15	9.3	5.9	3.7
2.0	46	32	20	12	7.8	4.9
2.5	58	40	25	16	9.8	6.2
3.0	69	47	30	19	12	7.4

SOURCE: EPA Federal Register LT2ESWTR: Proposed Rule Aug. 11, 2003.

CT-Table

For Inactivation of *Cryptosporidium*
Reaction Time "t" Can Vary[(1)] from:

- 3 to 30 Hours for Chlorine Dioxide (ClO_2)
- 10 to 30 Minutes for Ozone (O_3)
- 3 to 15 Seconds for UV

[(1)] Actual times will depend upon water temperature and residual concentration of disinfectant in water.

CT-Summary

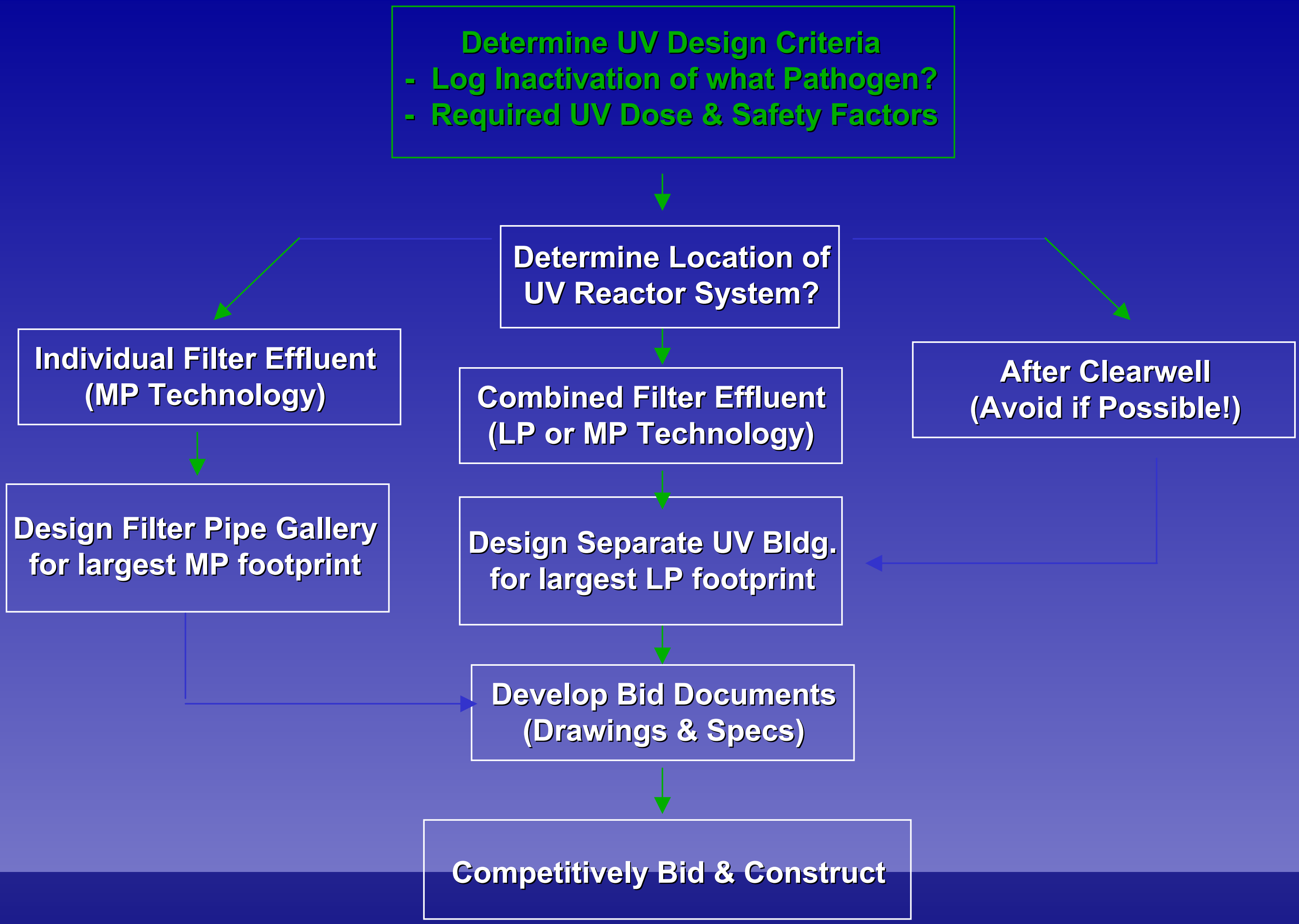
- USA:
- UV EPA Guidance Manual (Draft June 2003) different dose values are specified (based upon log credit for Crypto and Giardia)

Log Inactivatio n Credit	Crypto [mJ/cm2]	Giardia [mJ/cm2]	Virus [mJ/cm2]
0.5	6.8	6.6	55
1.0	11	9.7	81
1.5	15	13	110
2.0	21	20	139
2.5	28	26	169
3.0	36	34	199
3.5	-	-	227
4.0	-	-	259

- UV Equipment need to be validated (suggested protocol can be found in Guidance Manual)
- Surrogate organism: MS2 phage
- Validation location at the discretion of the engineer (advantages and disadvantages need to be evaluated)

Drinking Water UV Standard

UV SYSTEM DESIGN CRITERIA AND APPROACH



UV Design Process

System Design Considerations

- Space requirements?
- Available headloss for UV system / hydraulic profile?
- Ensure reactor inlet/outlet hydraulics match or exceed validation hydraulics?
- Ensure plant water quality match or exceed validation conditions?
- One sensor per lamp or approved lamp “zone”?
- Design elements to handle off-spec, off-line operation
  - Provision of overflow and/or bypass?
  - Provision of UPS for entire system?

Reduction Equivalent Dose (RED)

- **Calculated UV dose for UV reactor based on biodosimetry**
- **RED = UV dose in a collimated beam test that achieves the same inactivation of challenge microorganism as measured for UV reactor during biodosimetry testing**

UV DOSE

SOURCE: EPA Federal Register LT2ESWTR: Proposed Rule Aug. 11, 2003.

Log Inactivation Credit	*Cryptosporidium*		*Giardia*		*Virus*	
	LP Lamps	MP Lamps	LP Lamps	MP Lamps	LP Lamps	MP Lamps
0.5	6.8	7.7	6.6	7.5	55	63
1.0	11	12	9.7	11	81	94
1.5	15	17	13	15	110	128
2.0	21	24	20	23	139	161
2.5	28	32	26	30	169	195
3.0	36	42	34	40	199	231
3.5	--	--	--	--	227	263
4.0	--	--	--	--	259	300

Tier 1 RED Targets (mJ/cm^2) for UV Reactors

SOURCE: EPA UV Disinfection Guidance Manual, Proposed Draft, June 2003, pg 4-6.

UV Dose Safety Factor & Polychromatic Bias Calculations

Target Pathogen (typically Crypto)	
LT2ESWTR Log Inactivation Required	2
LT2ESWTR Dose Required (mJ/cm2)	6.0
Challenge Inactivation	
Number of Influent Samples	5
Influent Standard Deviation	0.2
Number of Effluent Sample	5
Effluent Standard Deviation	0.2
Challenge Log Inactivation	1
Challenge RED (mJ/cm2)	25
Collimated Beam	
Dose Calculation Uncertainty (%)	10
Dose-response Uncertainty (%)	10
Validation Sensors	
UV Intensity Uncertainty (%)	15
Flowmeter Uncertainty (%)	0
UVT Uncertainty (%)	10
WTP Sensors	
On-line UV Intensity Uncertainty (%)	15
Reference UV Intensity Uncertainty (%)	15
Flowmeter Uncertainty (%)	0
UVT Uncertainty (%)	10
Lamp Output	
Lamp Output Standard Deviation (%)	15
Number of Sensors	1
Number of Banks	1
Interpolation	
Interpolation Uncertainty (%)	10

(from Part 141.729(d) table of EPA Federal Register, Proposed Rule)

Safety Factor Calc

Polychromatic System Bias	1.0
RED Bias	2.45
Total Random Uncertainty (%)	43.83
Recommended UV Dose Safety Factor	**3.53**
Target RED UV Dose (mJ/cm2)	**20.47**

Very difficult to determine uncertanties

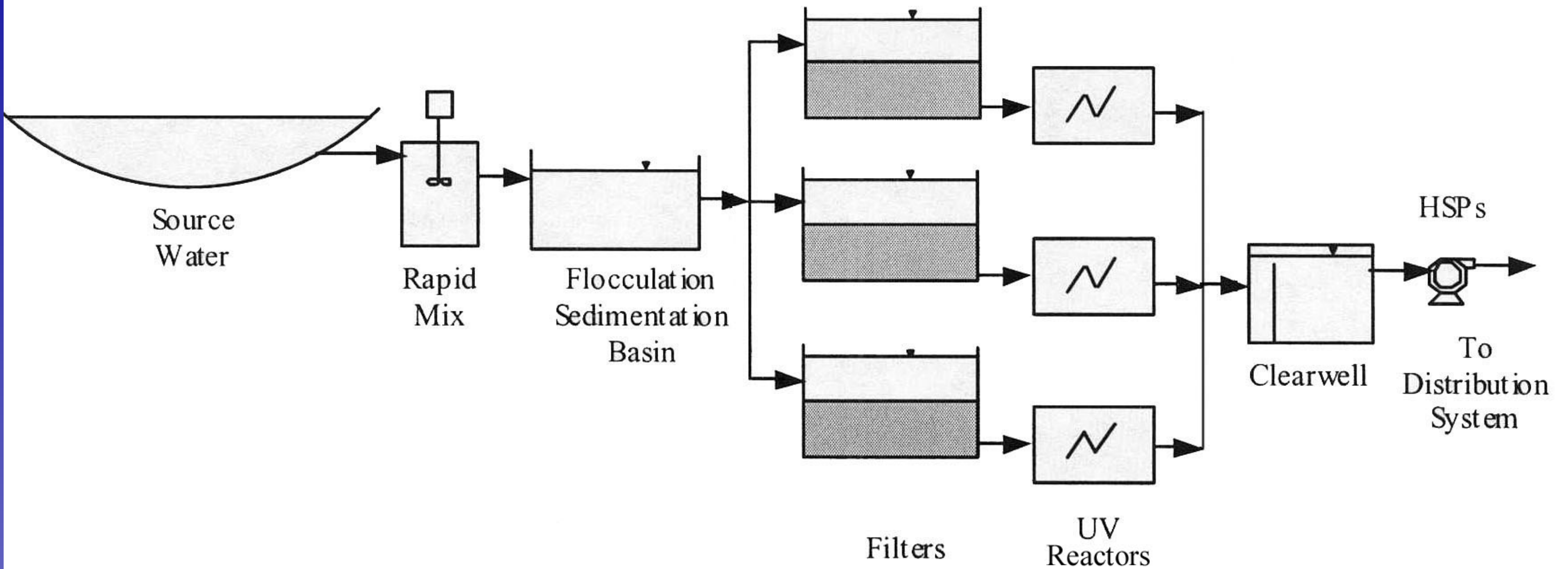
Tier 2 RED Target for UV Reactors

- **Individual filter effluent pipes?**
- **Combined filter effluent pipe?**
- **After clearwell?**

SOURCE: EPA UV Disinfection Guidance Manual, Proposed Draft, June 2003, pg 4-6.

Where to Install UV Reactors?

Reactor Installation on Individual Filter Effluent Piping (in Filter Gallery)



Individual Filter Location

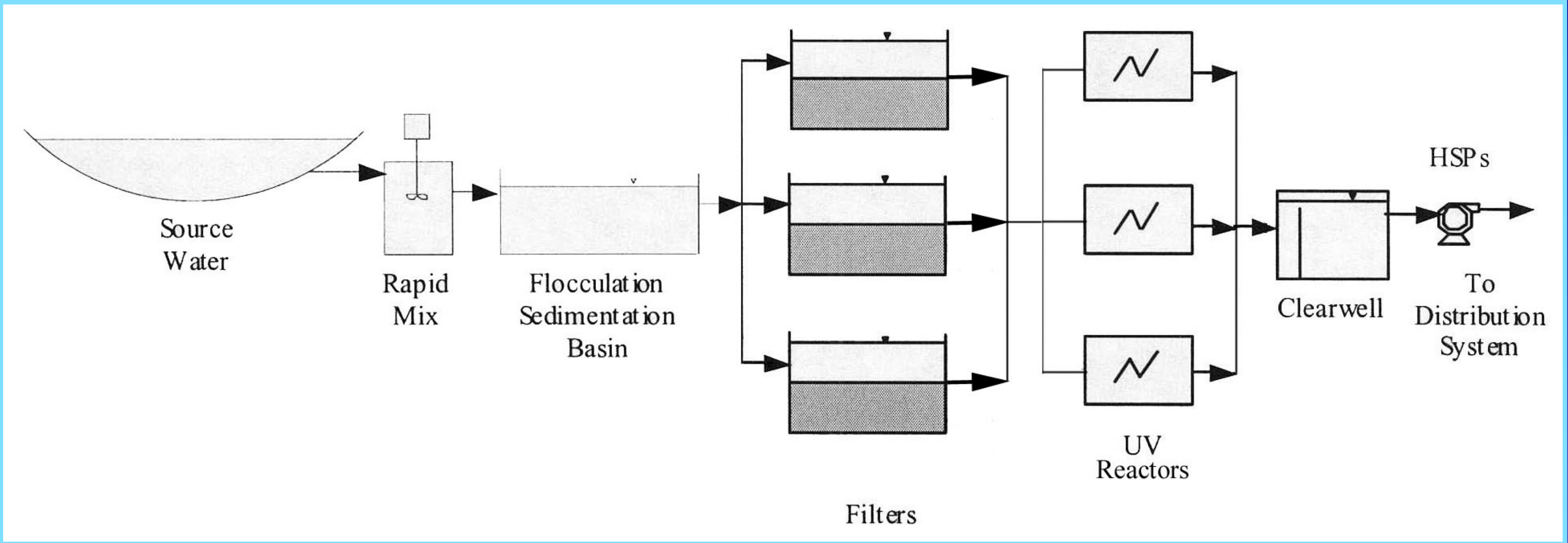
SOURCE: Other Source pg 3-7.

- Loss or maintenance on UV reactor requires filter shutdown
- No concern on flow split to reactors
- Problems with UV reactor shutdown during filter backwash

SOURCE: EPA UV Disinfection Guidance Manual, Proposed Draft, June 2003, pg 4-6.

Reactor Installation on Individual Filter Effluent Piping in Filter Gallery

Reactor Installation on Combined Filter Effluent (in Separate Structure)



SOURCE: EPA UV Disinfection Guidance Manual, Proposed Draft, June 2003, pg 4-6.

Combined Filter Effluent

- **Loss or maintenance on UV reactor does not require filter shutdown**
- **Practical with LP or MP reactors**
- **Concern on flow split to reactors**
- **No problems with UV reactor shutdown during filter backwash**

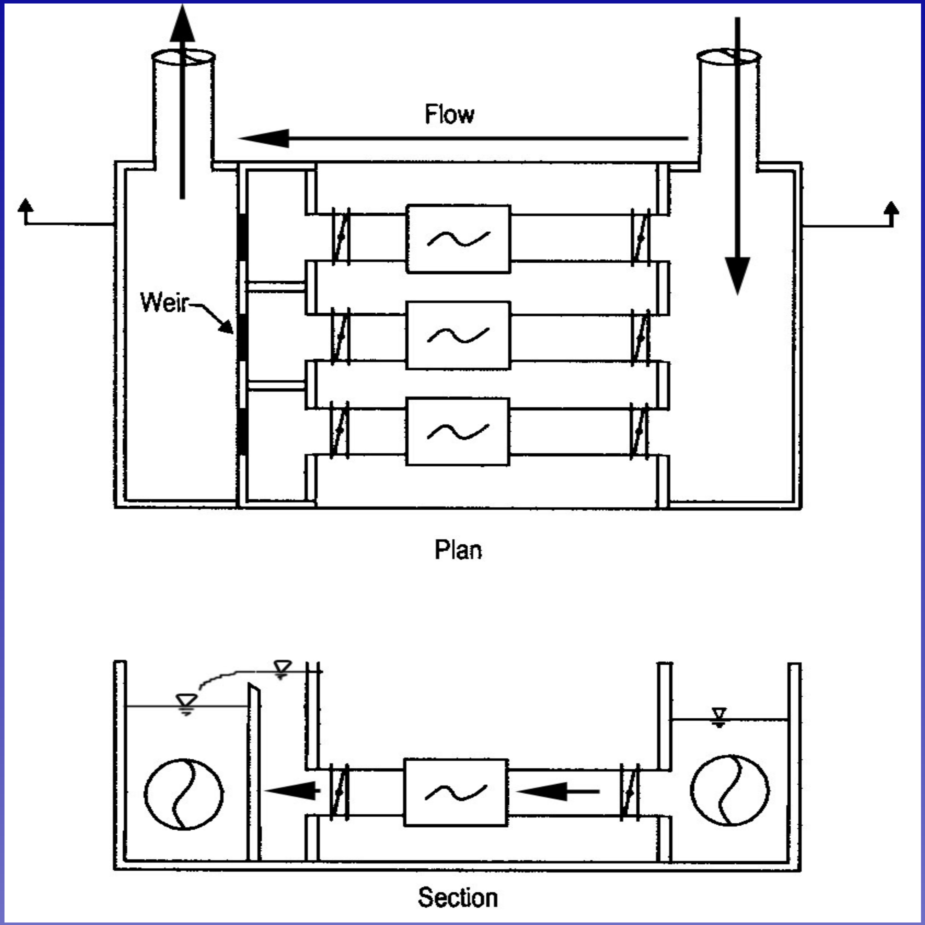
SOURCE: EPA UV Disinfection Guidance Manual, Proposed Draft, June 2003, pg 4-6.

Reactor Installation on Combined Filter Effluent (in Separate Structure)

- Greater fluctuations in flow rate
- Reactor cost higher due to increased pressure ratings
- Problems with surge / water hammer
- Greater concern over breakage of UV lamps & quartz sleeves
- UV reacts with free chlorine residual

Installation of UV after Clearwell Not Recommended

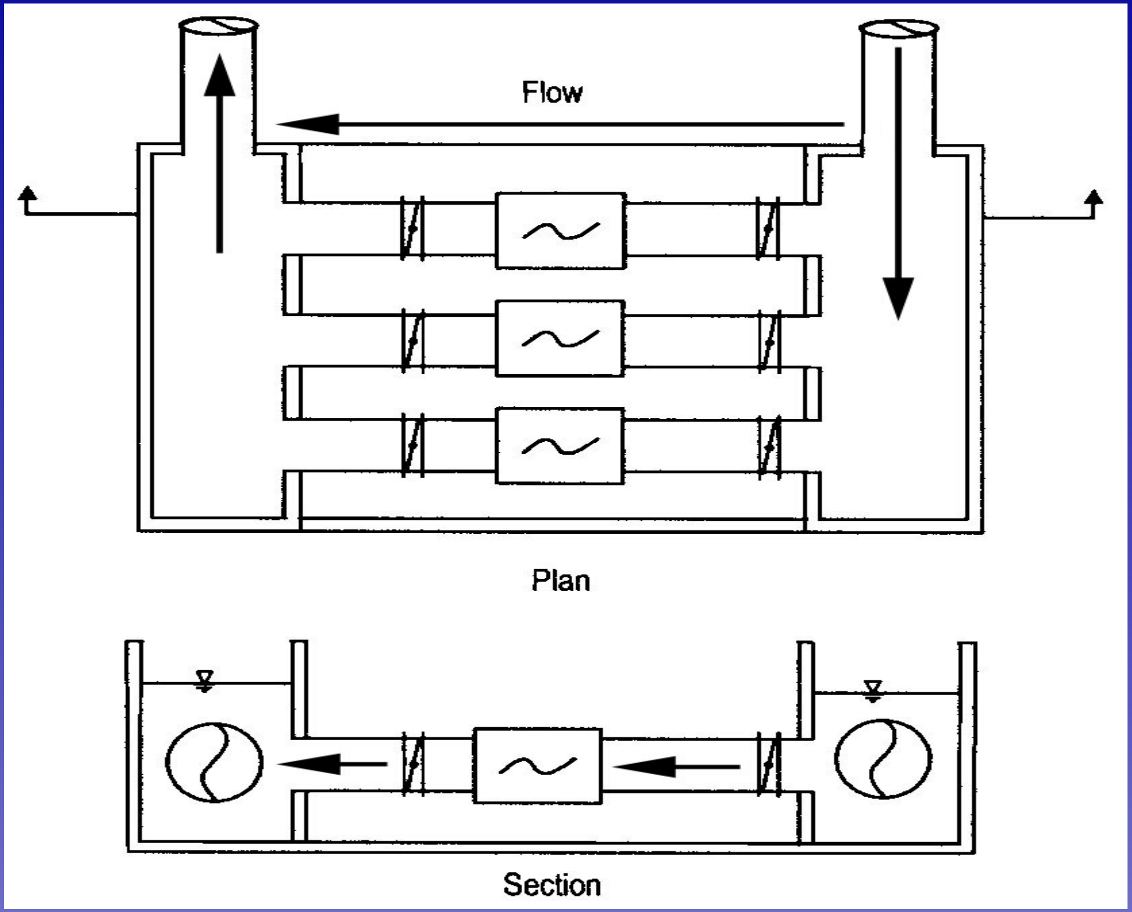
A. Effluent Weirs for Flow Split



SOURCE: EPA UV Disinfection Guidance Manual, Proposed Draft, June 2003, pg 3-33.

Multiple UV Units on Combined Filter Effluent

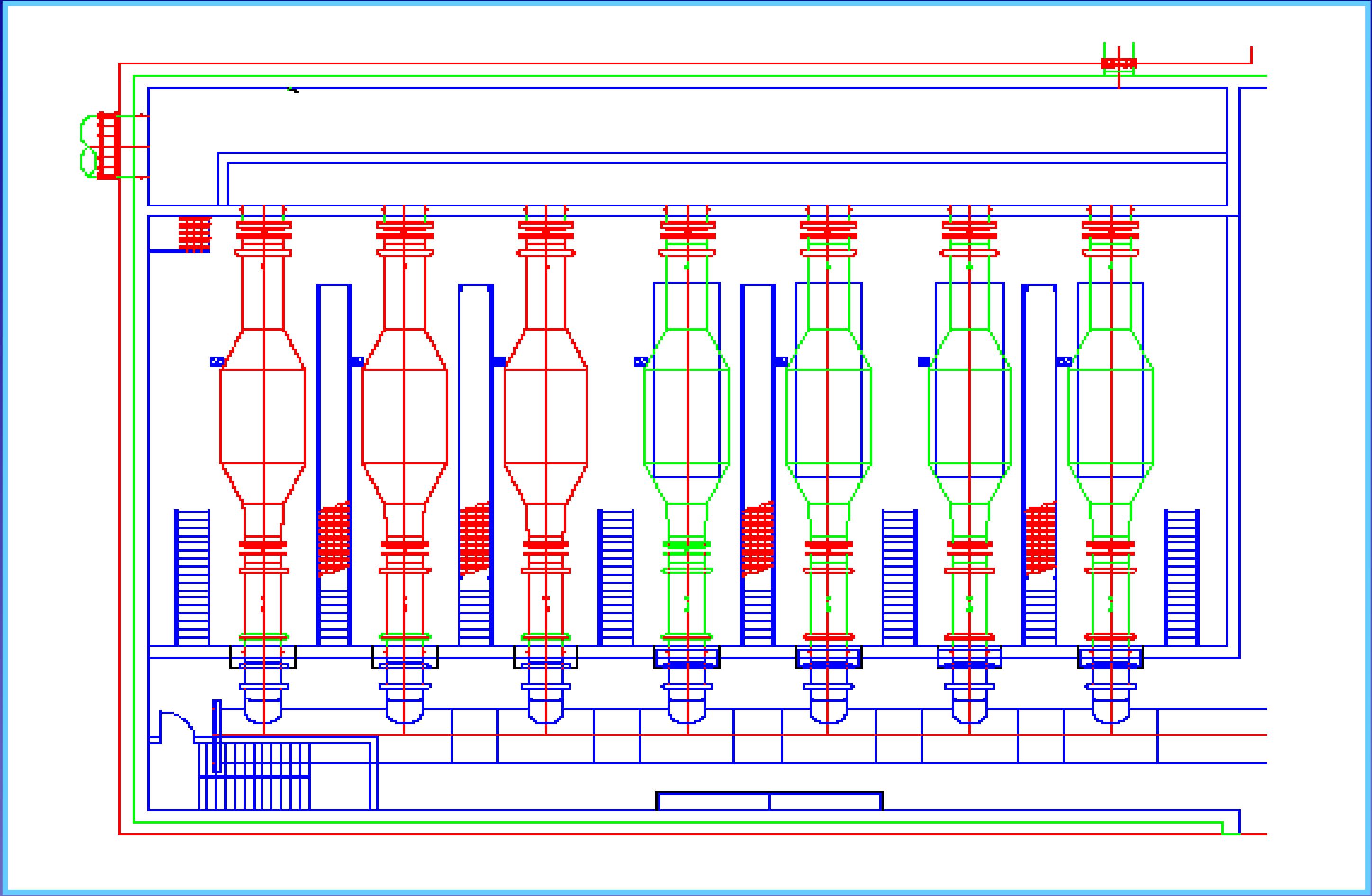
B. Influent Submerged Orifice for Flow Split



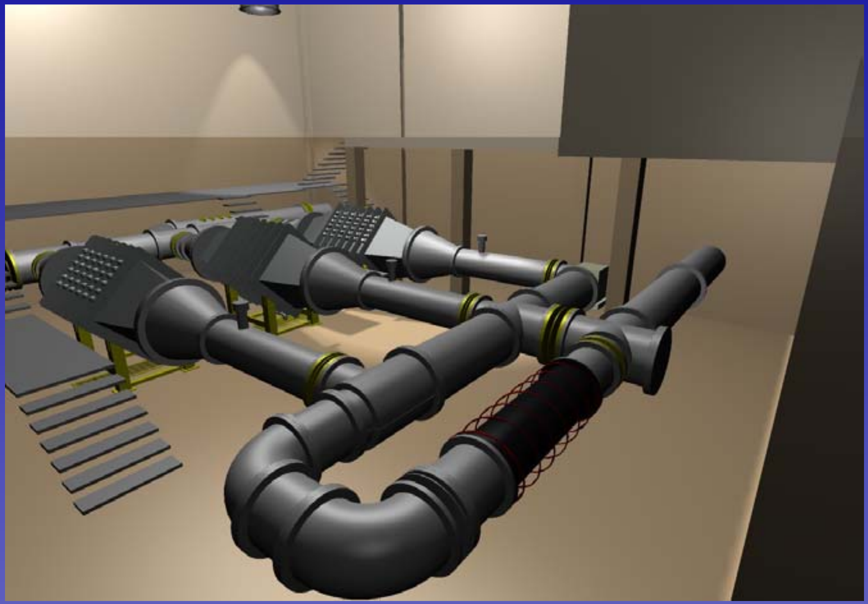
SOURCE: EPA UV Disinfection Guidance Manual, Proposed Draft, June 2003, pg 3-33.

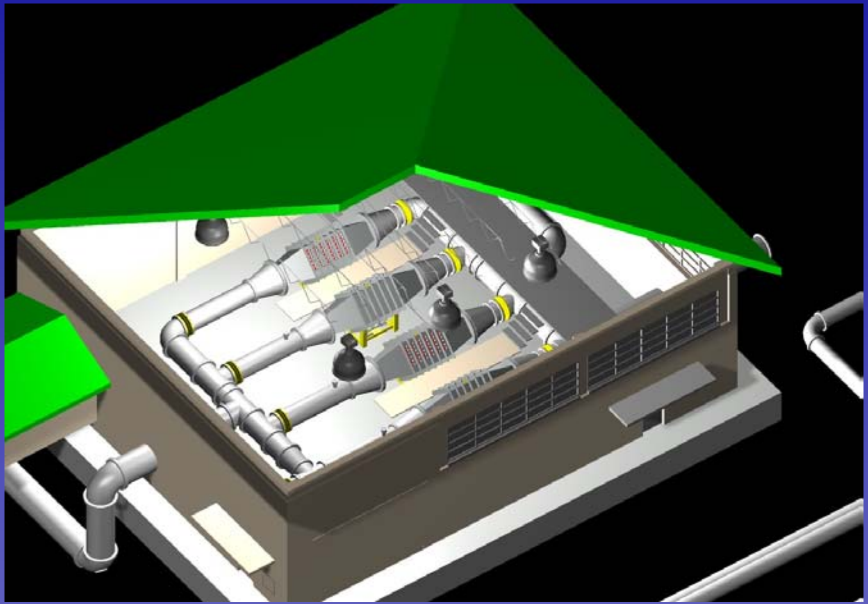
Multiple UV Units on Combined Filter Effluent

C. Influent Pipe Header w/Individual Meters for Flow Pacing



Multiple UV Units on Combined Filter Effluent





Typical Post Filtration Design

- Determining disinfection performance (i.e., delivered UV dose) of a reactor relative to operating parameters that can be monitored full-scale:
  - Water flow
  - Received UV intensity
  - UV transmittance

What is Reactor Validation?

- Provide confidence / verification that a given UV reactor and piping configuration can provide level of disinfection (inactivation) required
- Significant differences in following parameters effect reactor performance:
  - Hydraulics (piping & reactor design)
  - UV intensity monitoring (sensor # & placement)
  - Water quality (UV transmittance)
  - Flow rate

Why Perform Reactor Validation?

On-Site Validation at WTP

or

Off-Site Validation

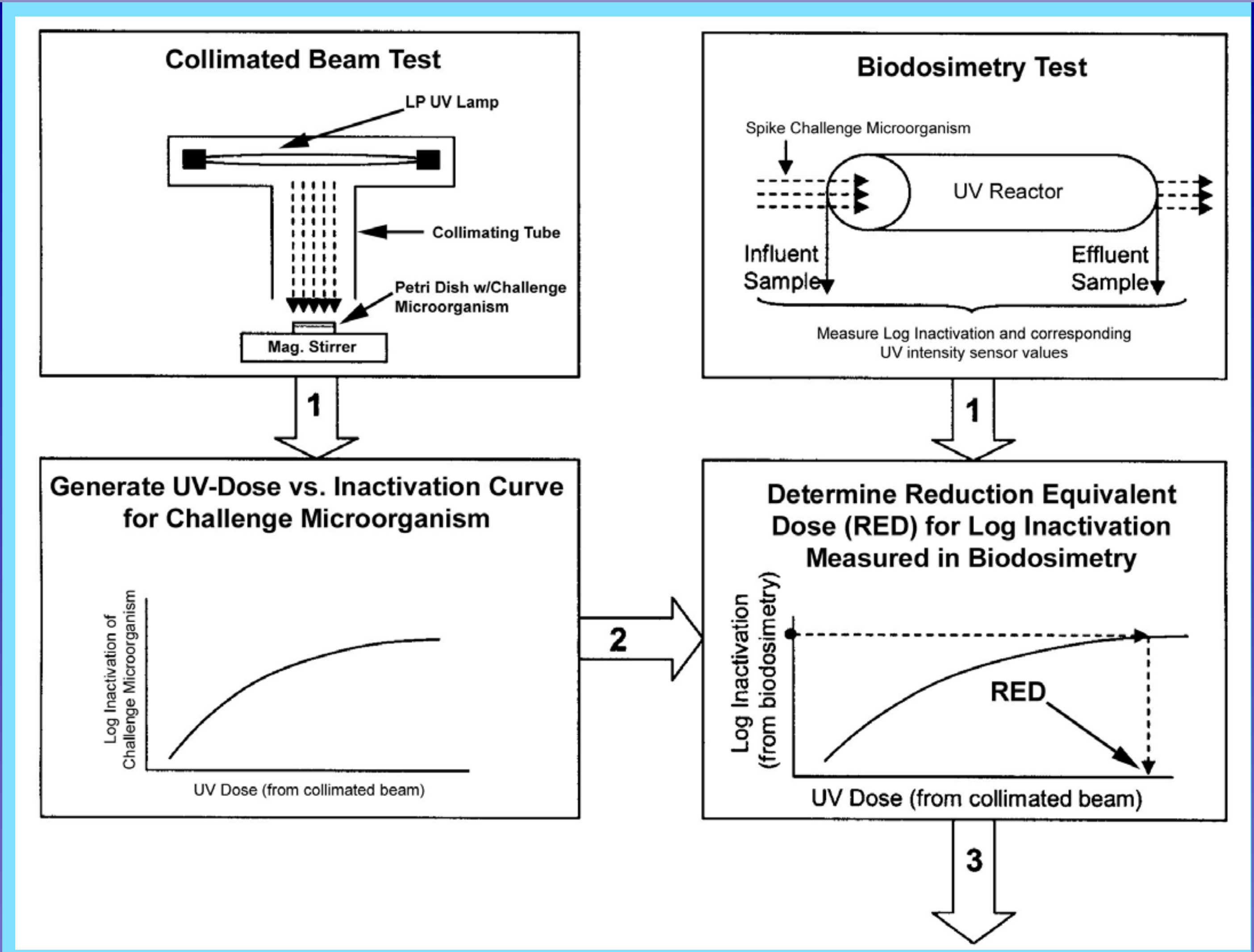
Where Can Vendor Perform Reactor Validation Testing?

- Sufficient water flow & quality (UVT)?
- Microbiology sampling and laboratory?
- Providing sufficient mixing of spiked microorganisms before and after reactor?
- Obtaining permits for disposal of test water?

On-Site Validation at WTP Expensive - Not Trivial!)

- Need to set up inlet & outlet piping conditions representative of those at WTP
- Duplicates of reactors can be validated
- Current validation facilities:
  - Germany
  - Portland, OR
  - New Jersey

Off-Site Reactor Validation



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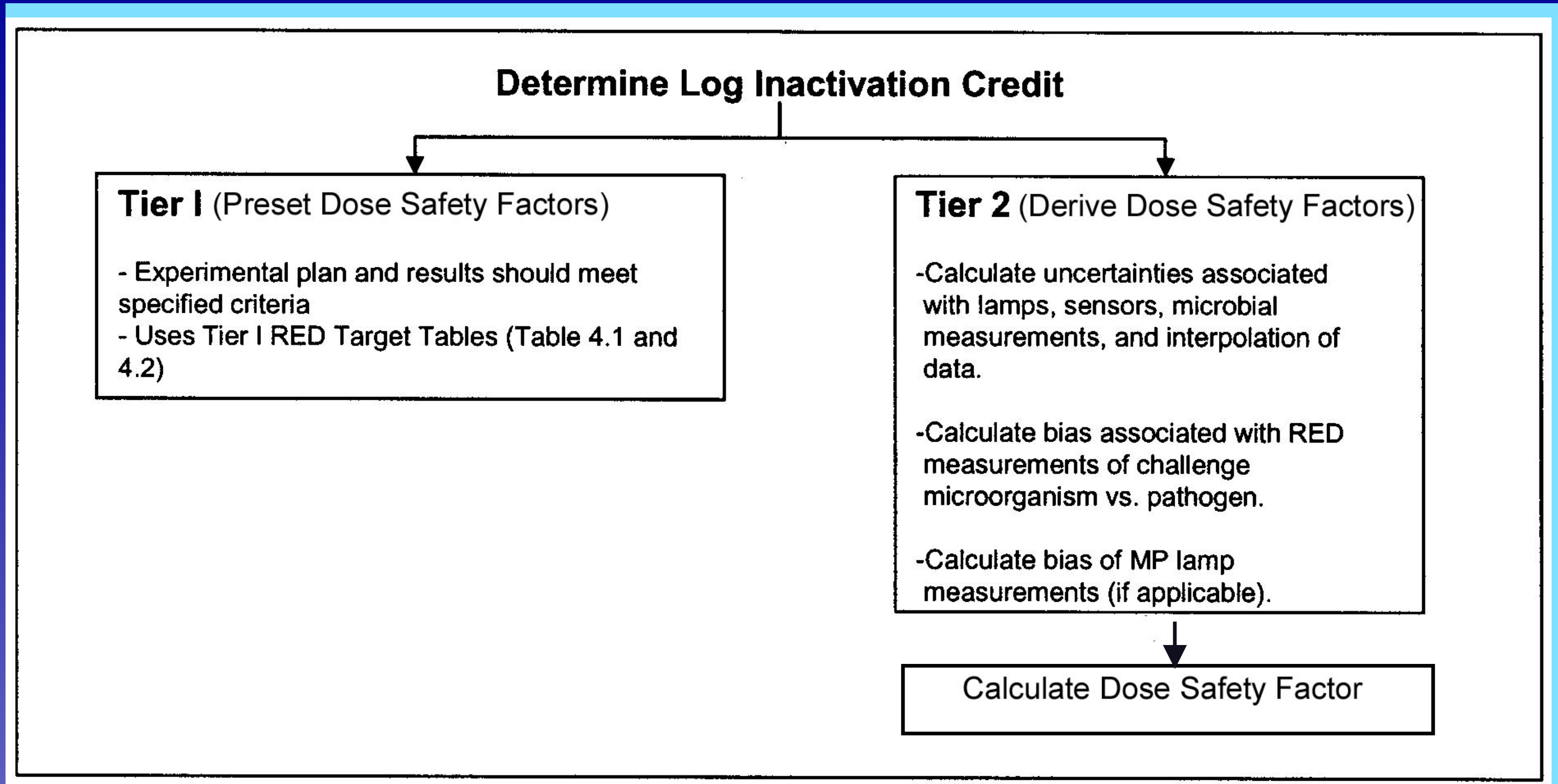
Steps of a Validation Process

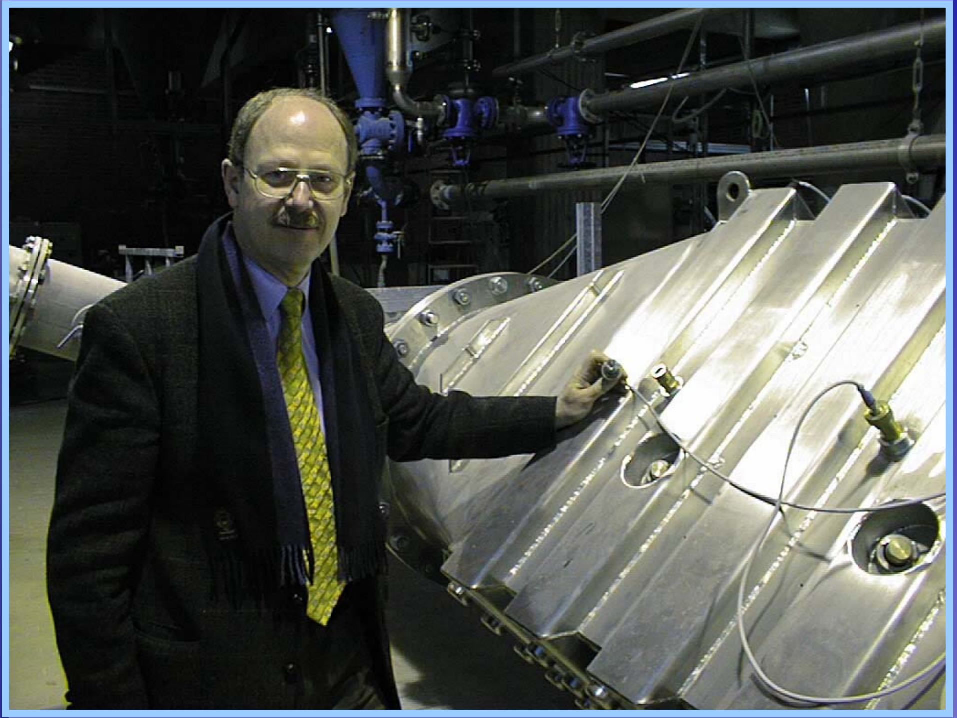


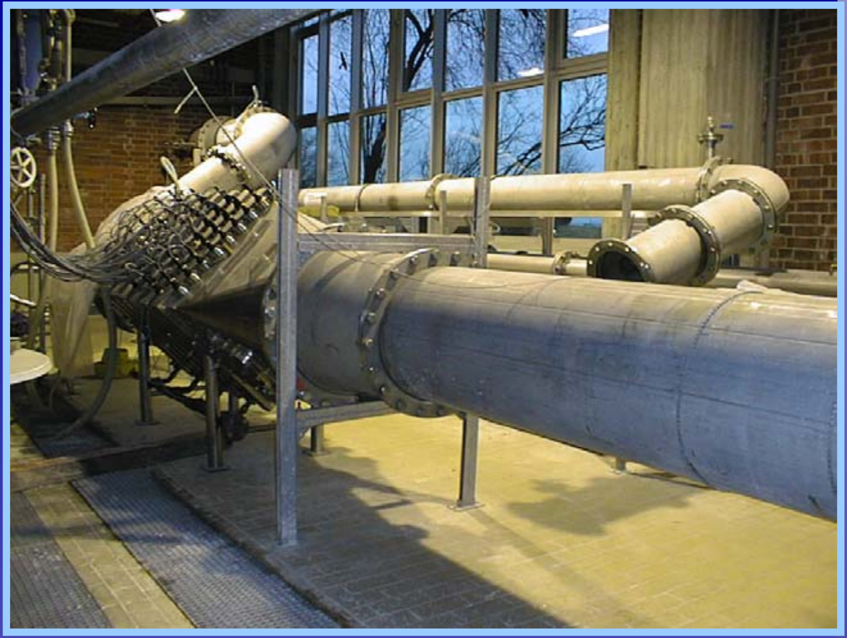
Steps of a Validation Process

- MP Reactors - min. of 1 sensor / lamp
  LP Reactors - min. of 1 sensor / row of lamps
- Spectral response requirements of intensity sensors (<10% of total light measured over 300 nm)
- See Appendix C of EPA UV, DGM (Draft) for other criteria on:
  - flow measurement
  - collimated beam apparatus
  - challenge microorganism dose-response
  - reactors using MP lamps
  - other

Tier 1 Reactor Validation Requirements

- 20 mgd max flow





German Reactor Validation Facility

- 40 mgd max flow, GW, no chlorine
- Discharge to Columbia River
- Validate as per US EPA Guid. Manual
- Microbiology – Clancy Environmental
- Testing (as of Sept. 2003):
  - WEDECO – 20 mgd reactor

Portland, OR - UV Validation Facility

- Unfiltered Systems
  - Min 95% water delivered / month treated w / UV within validation limits
- Filtered Systems
  - None specified by LT2ESWTR - Proposed Rule
  - States may establish requirements

LT2ESWTR Limits on Delivery of "Off-Spec" Water

(not operating within validation limits)

- Daily operations: walk-thru & equipment check
- **Lamp replacement ea. ~12,000 hrs for LP lamps**
- **Lamp replacement ea. ~6,000 hrs for MP lamps**
- **Ballast replacement ea. 4-8 years?**
- **Manual or auto quartz sleeve acid cleaning**
  - **Frequency depends on water quality at reactors (hardness, pH) and lamp operating temperature**

UV System Maintenance

- Capital Costs
  - **equipment, building, engineering, construction management, contingency**
  - **$0.05 to $0.07 per gallon of installed capacity, or $50,000 to $70,000 per million gallons of capacity**
- O&M Costs
  - **electricity ($0.05 / kw-hr), parts, labor and overhead cost of $0.004 to $0.008 per thousand gallons produced, or $4 to $8 per million gallons produced**
- Potential Patent Cost for *Cryptosporidium* Inactivation
  - **$0.015 per thousand gallons produced, or $15 per million gallons produced**

    10 mgd for 365 days = $55,000 / yr

Estimated Capital and O&M Costs

- UV can be an economical solution for *Cryptosporidium* Inactivation compared to chemical disinfectants
- Presently ascending large installations in U.S., and numbers are growing considerably
- UV technology is developing - greater efficiencies in future should lower capital and O&M costs

Conclusion

THANK YOU!