

**Scan QR code to log your
attendance for today's
(Thursday, June 18th)
breakout session**





Annual Users' Conference

**ADVANCING RADIATION SAFETY.
EMPOWERING PROGRESS.**

M Resort, Henderson, NV | June 15 – June 18



MIRION
TECHNOLOGIES

*Advancing Radiation Safety.
Empowering Progress.*

© 2026 Mirion Technologies. All rights reserved.

Radiation-Tolerant Imaging: *Evaluating Safety & Accuracy*

Dylan Palmer

Business Development Manager

Mirion Connect | Annual Users' Conference 2026

Henderson, NV

Nuclear Cameras



Imaging Inspections

- *Cameras are often used (& mis-used) in both process monitoring as well as inspection applications.*
- *To be successful, it's important to understand the benefits & trade-offs of various imaging technologies; whether from the standpoint of radiation tolerance, size, color, optics, connectivity, or other key attributes.*
- *In addition, how you choose to integrate cameras into your workflow can make the difference between success & frustration..*

Agenda



Why do we
inspect



What we
want to
see/not see



Why does it
matter



How it all
works



Key
considerations



Discussion

Our Values



We Understand Your Challenges

Delivering confident visibility. Our radiation-tolerant cameras deliver critical protection through confident visibility in the most extreme environments

*We design & manufacture imaging systems for inspection, surveillance & monitoring in industries as diverse as Nuclear power plants, reprocessing & decommissioning. With **thousands of systems** in use worldwide, Mirion has more than **35 years of experience** in serving global markets -- & delivering **unrivalled support & expertise** to address our clients' needs. Mirion products are industry recognised for **performance, quality & reliability**.*

Radiation Tolerant Cameras



Why are they Required

- *By-products of the nuclear industry (radioactive waste) are hazardous to humans, animals, & the environment*
- *To ensure the continued safe use & disposal of radioactive waste, processes must be surveyed:*
 - *Reactor core & fuel assemblies*
 - *Power stations & waste processing equipment*
 - *Fuel storage ponds & spent fuel condition*
 - *Waste vaults & transfer routes*
 - *Accident zones (Chernobyl, Fukushima)*
 - *Equipment which are used in fuel cycle*
- *Nuclear licensed sites legally bound to justify plants are safe to operate, requiring continuous inspection & reporting. Visual surveying is one key factor in justification & preventative maintenance*
- *Due to detrimental effects radiation has on humans, inspection & surveillance must be carried out remotely*
- *Electronics will fail due to radiation damage, so radiation-hardened equipment is needed to extend the operating life*

Applications



Radiation Tolerant Cameras provide a full spectrum of low, medium & high dose solutions to every stage of the nuclear fuel cycle

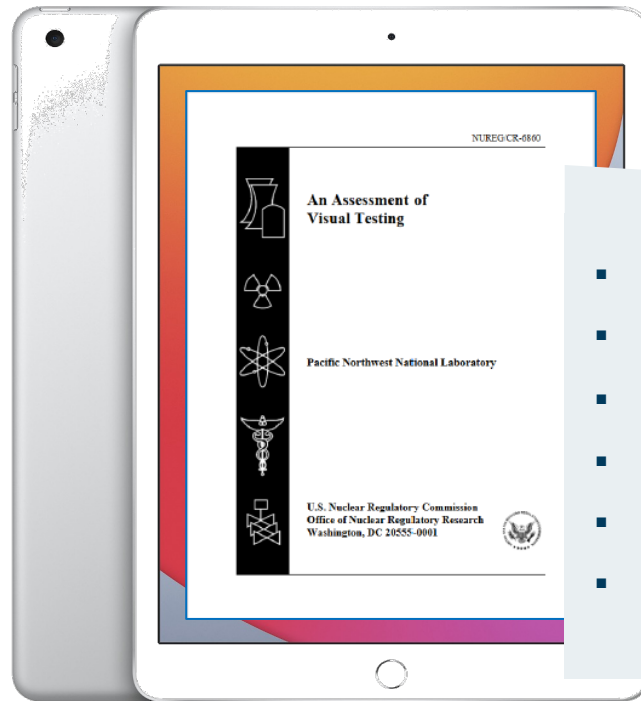
- *Operating NPPs – Maintenance, ALARA/HP, Refueling/Fuel Handling, New Build*
- *Waste Management & Decommissioning*
- *Inspection & Outage Support*
- *Surveillance & Security*

- ✓ *Viewing inaccessible areas & processes*
- ✓ *Safety, personnel dose reduction ALARP/ALARA*
- ✓ *Radiological & Chemical Hazards*
- ✓ *'Baseline' data acquisition requirements*
- ✓ *Safeguards*
- ✓ *Identification*
- ✓ *Navigation, Positioning & Alignment*
- ✓ *FOSAR*
- ✓ *Remote Handling & Robotics*
- ✓ *PLIM & PLEX*

Why Do We Inspect



What We Want to See



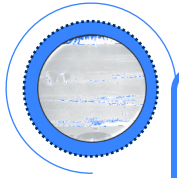
- Cracking
- Integrity concerns
- Material Degradation
- Caustic accumulation
- Heat effected zones
- Colour indicators



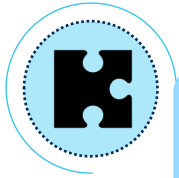
What we DON'T Want to See



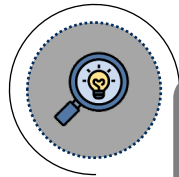
Crud lines that resemble cracks



Machining marks that resemble weld issues



Non-threatening surface imperfections in the material



Previously researched anomalies



Why Does it Matter?



Radiation Tolerant Camera Applications



	C911 Dotcam	RC913 Mini-PTZ	C981/C983	RC720 HD-RAD		RC911 Dotcam - HR	SC985	R985	R981 Compact	Hyperion Compact	R93	R941	R942
													
													
Total Dose	100 Gy (1 x 10 ⁴ rad)	100 Gy (1 x 10 ⁴ rad)	100 Gy (1 x 10 ⁴ rad)	500 Gy (5 x 10 ⁴ rad)	500 Gy (5 x 10 ⁴ rad)	1k Gy (1 x 10 ⁵ rad)	10kGy (1 Mrad) [¹³⁷ Cs]	100k Gy (1 x 10 ⁷ rad)	1 MGy (1 x 10 ⁸ rad)	1 MGy (1 x 10 ⁸ rad) Cobalt-60	2 MGy [⁶⁰ Co] (2 x 10 ⁸ rads) Cobalt-60	2 MGy [⁶⁰ Co] (2 x 10 ⁸ rads) Cobalt-60	2 MGy [⁶⁰ Co] (2 x 10 ⁸ rads) Cobalt-60
Dose Rate	100 Gy/h (1 x 10 ⁴ rad/h)	100 Gy/h (1 x 10 ⁴ rad/h)	100 Gy/h (1 x 10 ⁴ rad/h)	100 Gy/h (1 x 10 ⁴ rad/h)	100 Gy/h (1 x 10 ⁴ rad/h)	300 Gy/h (3 x 10 ⁴ rad/h)	1kGy/h (100k rad/h)	1kGy/h (1 x 10 ⁵ rad/h)	1 kGy/h (1 x 10 ⁵ rad/h) Chalnicon	1 kGy/h (1 x 10 ⁵ rad/h)	1 kGy/h (1 x 10 ⁵ rad/h) Chalnicon	1 kGy/h (1 x 10 ⁵ rad/h) Chalnicon	1 kGy/h (1 x 10 ⁵ rad/h) Chalnicon



Low Radiation Environments

Typical of short inspection cycles (minimum exposure) &/or brand new fuel/very old fuel:

- Pipes & bore holes
- Storage ponds
- Residual radioactive environments
- Ad-Hoc process monitoring
- Remote inspection



Medium Radiation Environments

Cameras with flexibility for a variety of environments:

- Decommissioning inspections
- Waste processing & segregation
- Ad-Hoc process monitoring
- Remote inspection



High Radiation Environments

Cameras with uncompromising radiation tolerance designed for prolonged use in high radioactive environments:

- Hot cells
- Reactor cores
- Waste processing & segregation
- Remote inspection

Camera Controller / VMS

19" Rack Mount Controller



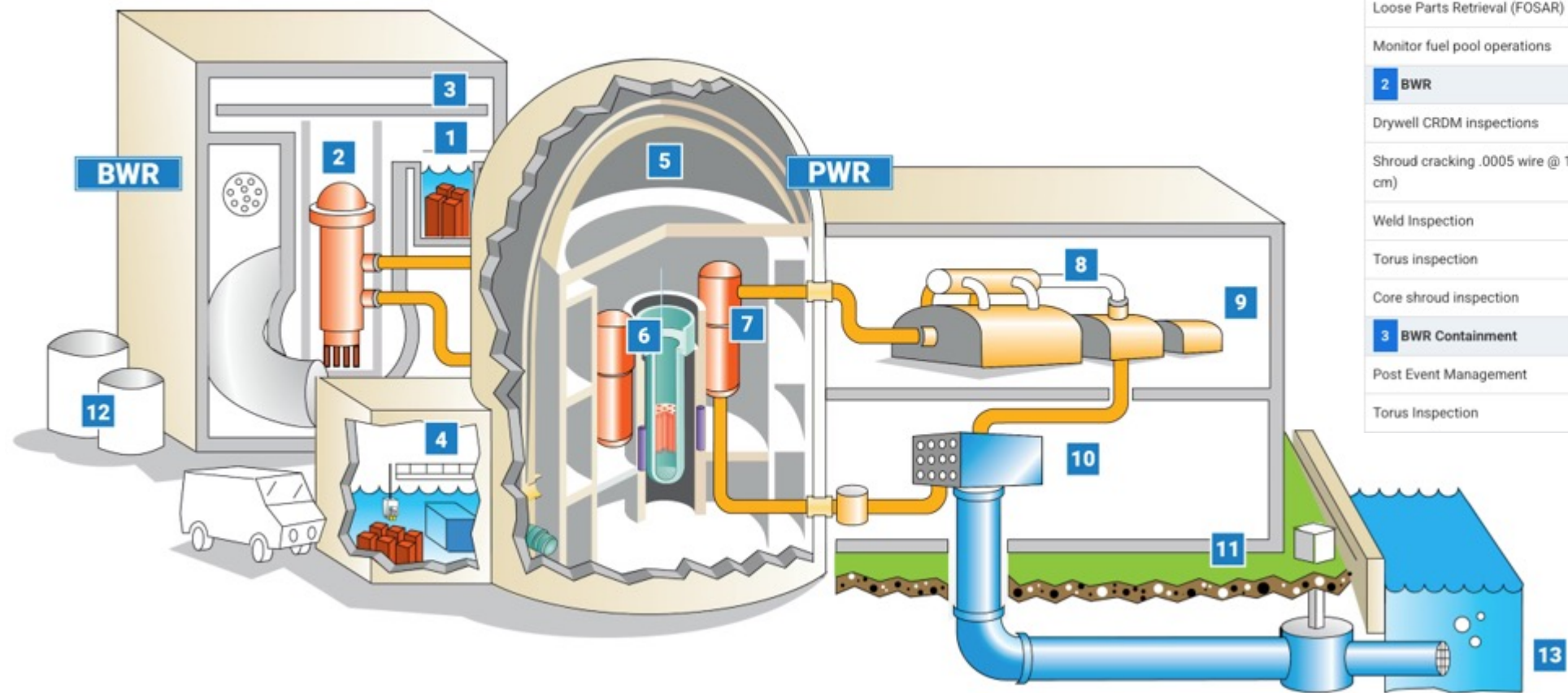
- *To achieve required level of radiation tolerance the amount of circuitry in cameras is minimized by locating this within the camera controller*
- *The camera controller is traditionally a 19" rack mounted box which supports 1–8 cameras*

Portable Pelicase Controller



- *Cameras designed for mobile inspection (Dotcam, Mini PTZ, HD-RAD) utilize Pelicase controllers*
- *These are portable all in one devices featuring:*
 - *Screens*
 - *Camera controls*
 - *Input / Outputs*
 - *Recording Functionality options*

Nuclear Plant Camera Uses



Inspection	Equipment
1 BWR Fuel Applications	
Inspect condition of fuel	<u>R93, R941, Hyperion Compact, HD-RAD, R981 Compact</u>
View Serial Numbers	
Loose Parts Retrieval (FOSAR)	
Monitor fuel pool operations	
2 BWR	
Drywell CRDM inspections	<u>Hyperion Compact</u>
Shroud cracking .0005 wire @ 12" (30 cm)	<u>R93, R941, HD-RAD</u>
Weld Inspection	
Torus inspection	<u>HD-RAD, R941, R981 Compact</u>
Core shroud inspection	
3 BWR Containment	
Post Event Management	<u>Hyperion Compact, SC985</u>
Torus Inspection	<u>Hyperion Compact</u>

Factors to Consider in Selecting the Right Camera



Nuclear Cameras by Application



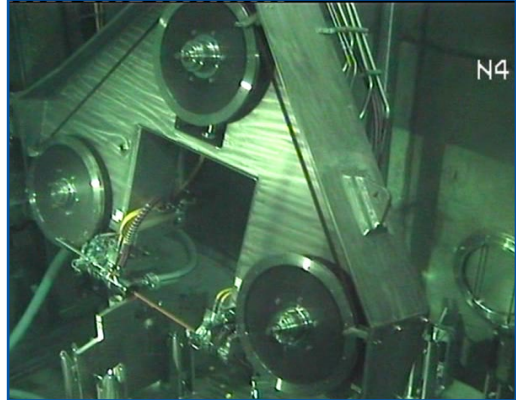
Nuclear Surveillance Systems

Camera	Model	Radiation Tolerance
	Hyperion Compact Gen II	High
	R981Compact	High
	R942	High
	SC985 HR	Medium
	C981	Low

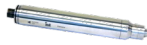
Typical Applications

- *Safety & Security (fuel handling route)*
- *ALARA/ALARP*
- *In-Containment /Post event monitoring*
- *Ponds/pools and storage facilities*
- *Hot Cell monitoring*
- *Cranes & Bridges*
- *Reprocessing & Vitrification*
- *Robotics and Manipulators*
- *Critical component monitoring*
- *Fuel dismantling/processing*

Nuclear Cameras by Application



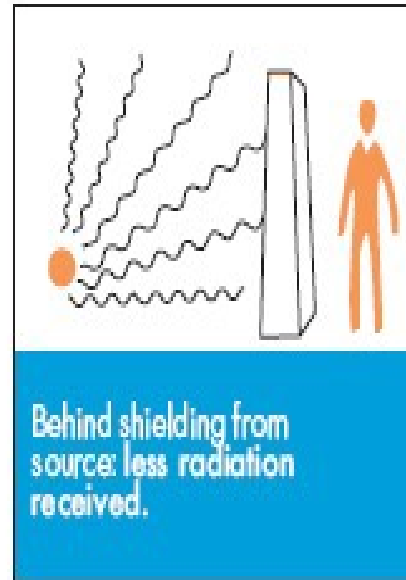
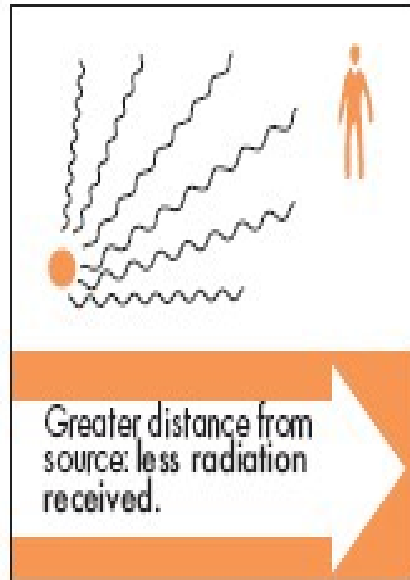
Nuclear Inspection Systems

Camera	Model	Radiation Tolerance
	R93 Camera	High
	R941 Camera	High
	RC720 HD RAD	Medium
	RC911 Dotcam HR	Medium
	RC913 Mini PTZ Mk II	Low
	C911 Dotcam	Low

Typical Applications

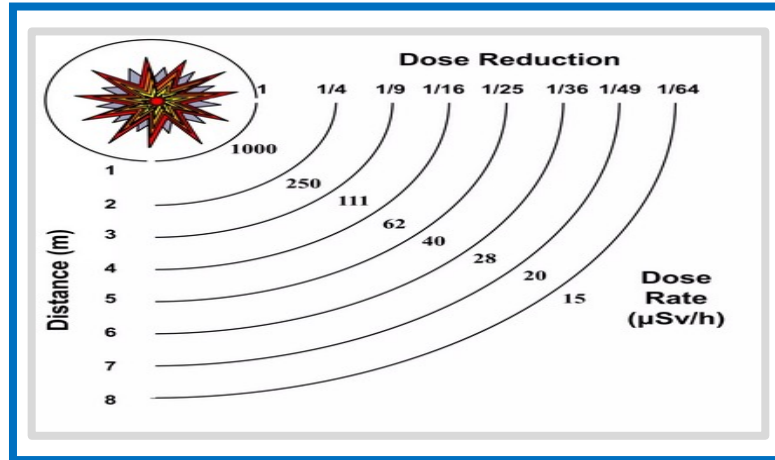
- Fuel handling & identification (Wet & Dry)
- Remote Handling
- Steering and alignment
- FOSAR
- In Service Inspection
- PLIM & PLEX Surveys
- Robotics and Manipulators
- Critical component monitoring
- Fuel dismantling/processing

Radiation Tolerance



- *Some things don't change:*
 - *Time, Distance, & Shielding*
- *Must consider both cumulative dose & dynamic dose*
- *More importantly need to understand use & workflow*

Radiation Tolerance: Distance



Distance Trade-offs

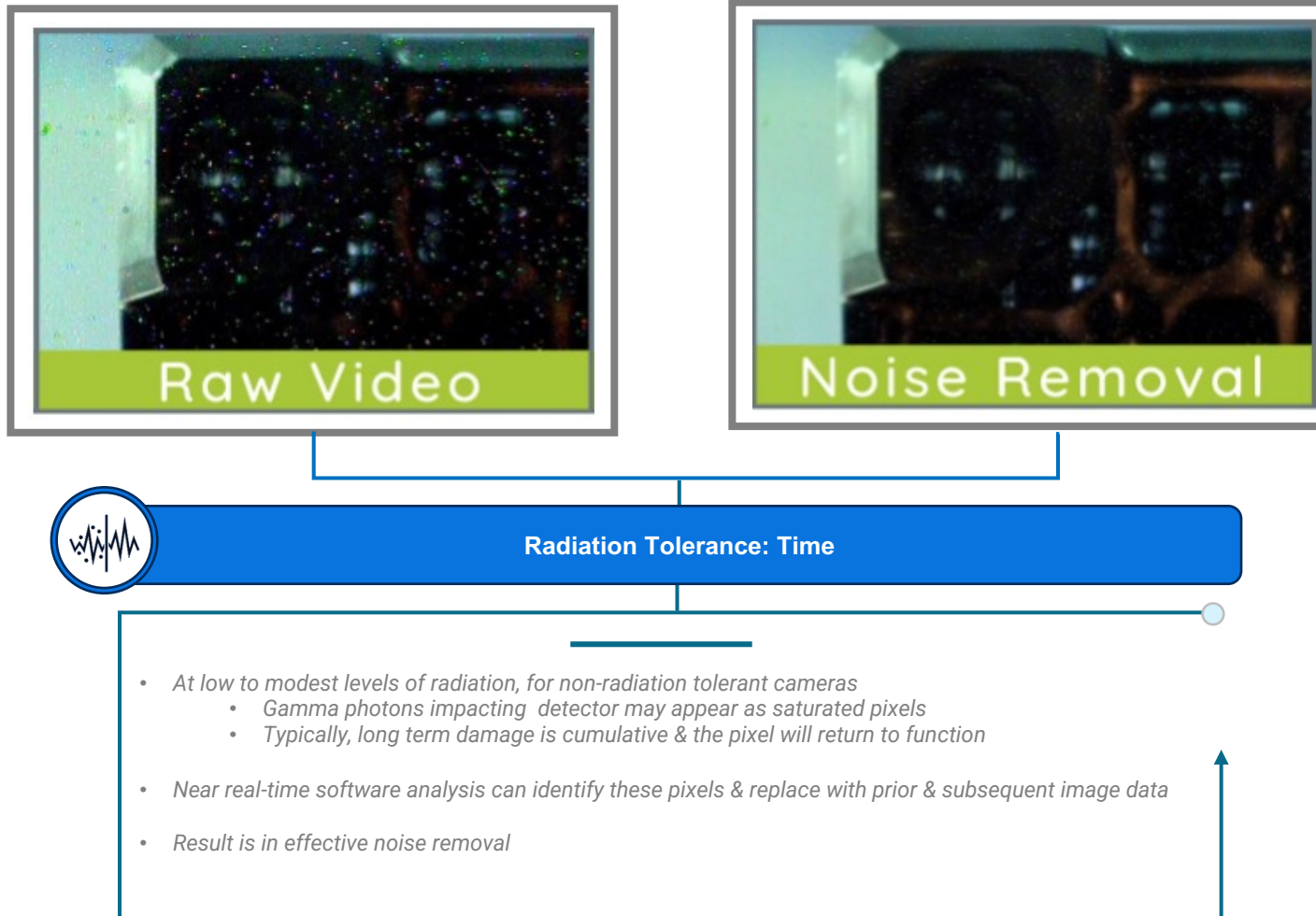
- Distance trade-offs
 - Vibration & image instability prevalent in air as distance from pan/tilt increases
 - **Compensate with lenses: Zoom, Narrow Angle**
 - But remember double the distance will quarter the radiation



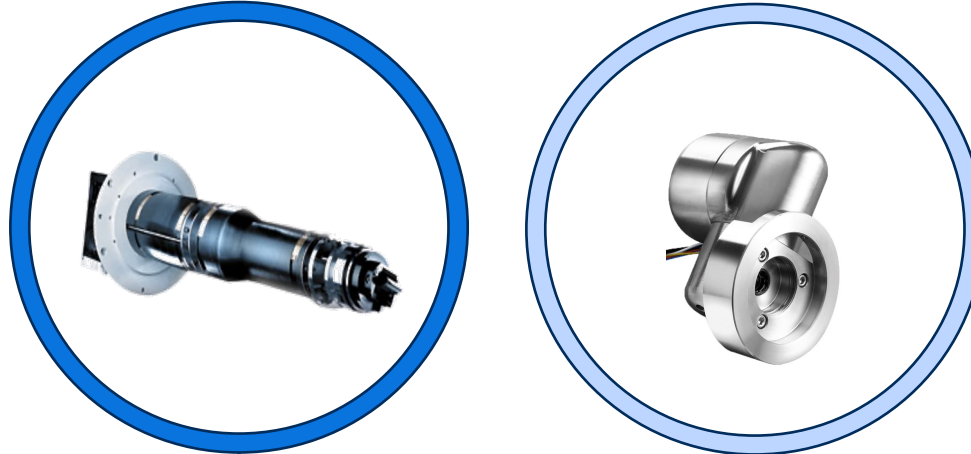
Thermal Trade-offs

- Thermal trade-offs
 - More prevalent in underwater inspections
 - Causes "waving" distortion across video image
 - Can significantly "hide" fine details
 - Software exists

Radiation Tolerance: Time



Radiation Tolerance: Shielding

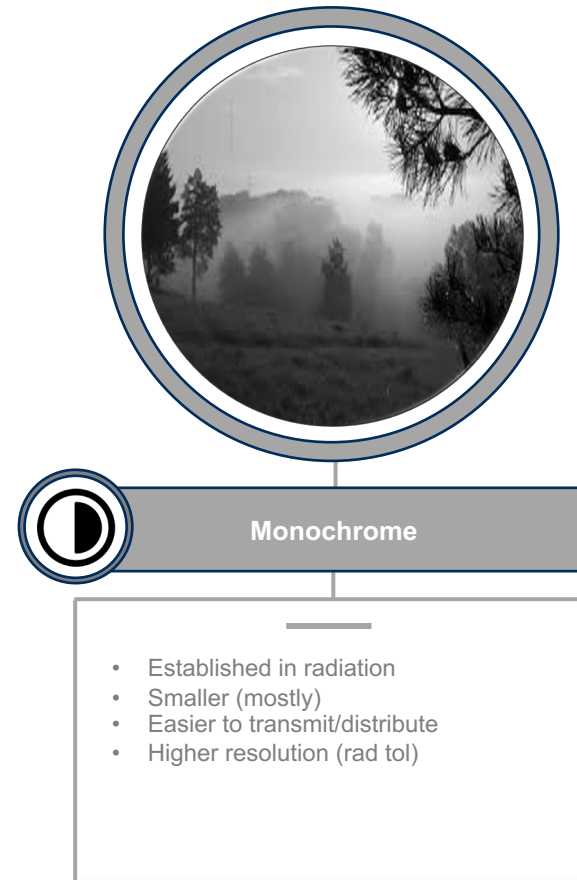


Shielding not as simple as placing a camera in the centre of high-Z material

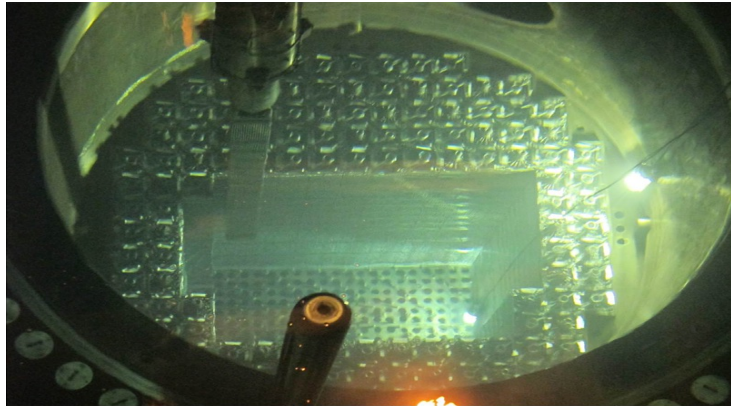
Camera often directed at the source for most of its useful acquisition

- **Various methods for shielding**
 - *Embedded imager & optics within a shielded housing*
 - *Imager in shielded housing with right angle viewing mechanism*
 - *Utilize shielded material (i.e. fused quartz silica blocks) with electronics located outside radiation area*
 - *The camera to self shield by "turning around"*
- *Primary trade-off is weight*

Color vs Monochrome



Size & Access



Deploy & Retrieve

- Some camera deployments are well known, planned, & optimized
- **Reactor inspection underwater deployed from the refuel bridge**
- Others are more difficult
 - Limited access hot cell with air lock tele manipulator positioning
 - Limited access glovebox



Size Matters

- Inspections carried out in limited access areas
- Often no external lighting sources
- Design/Impacts
 - Entry/egress of equipment/people
 - Size of optics
 - Size/heat dissipation of lighting

Optics – Radiation Impacts Design

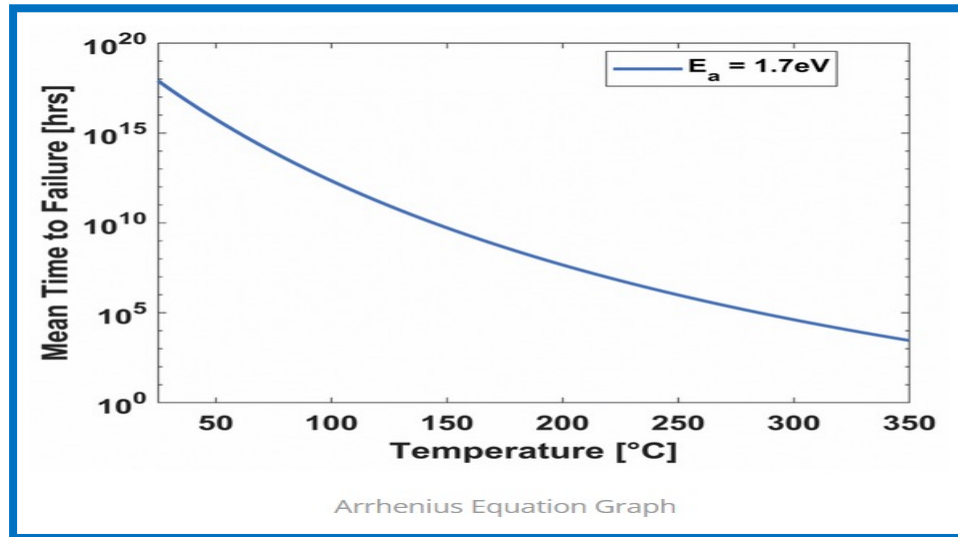


Optics

- **Radiation tolerant lens materials**
- **Non-browning**
 - Typically achieved through Cerium Oxide doping
 - *Non-browning* lenses can be produced, but are often higher cost



Temperature Impacts



Temperature – Imaging Impacts

- Elevated temp provides several challenges for all cameras
- Component life is shortened
- Many cameras packaged in stainless steel (15 watts / kelvin / meter)
- General rule of thumb: 50% reduction in lifetime for every 10°C rise when discussing semiconductor devices
- Lighting can “self heat” & add to the thermal sources

Lighting

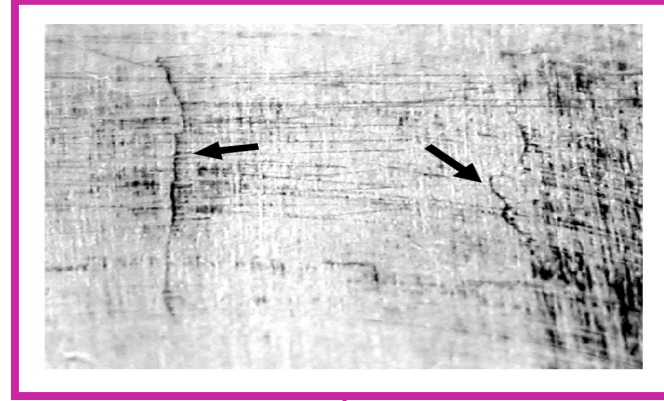


Light & Direction



Light & Light Direction

- Axial/in-line lighting versus offset lighting
 - Relief viewing for highlighting depth
- Polarizing filter
 - Reduce glare (air/water interface effects)
- Independent adjustability of lighting
 - Provide "3rd dimension"



Light & Light Direction

- Offset lighting highlights crack paths
- Just above right arrow, however, "hides" lateral portion of crack migration
- Lighting adjustability remains key in inspections

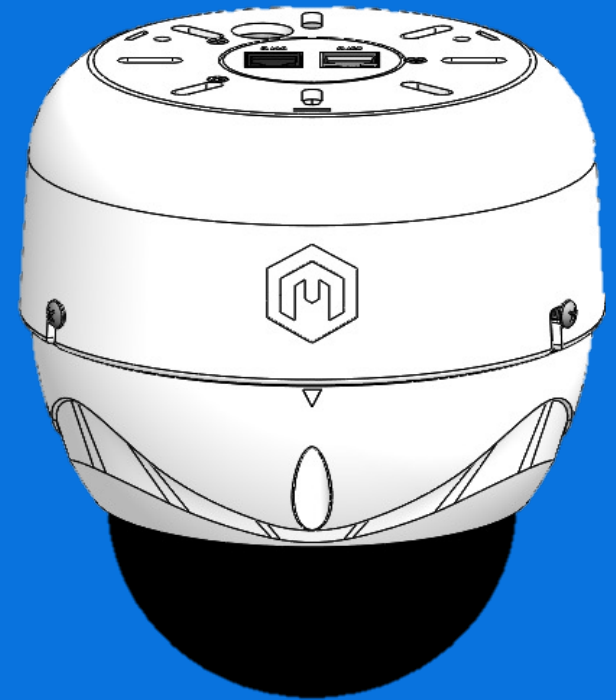
Closing Thoughts



Five Questions to ask:

- 1 What do you want to see?
(or, sometimes – What don't you want to see)
- 2 Expected Dynamic/Cumulative Dose (how much of what & how long)
- 3 How are you going to get the camera in/out
- 4 Existing cabling, penetrations, access to the signal
- 5 What do you want in your control room / operator station & where else do you want to view/archive the video

NuClear™ 400



NuClear™ 400

Confidence

01



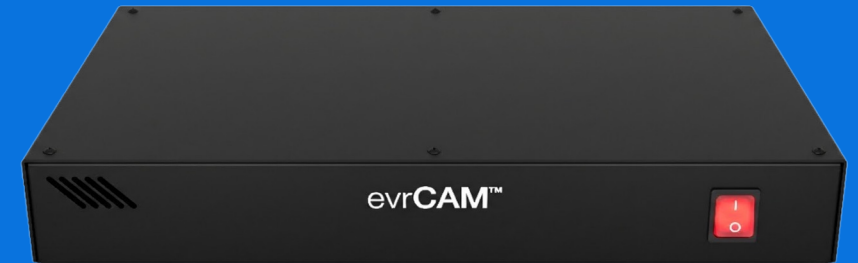
- *Exceptional picture quality in low light environment*
- *Built to withstand 400 Gy*
- *No perceivable change in picture quality after 100 Gy*
- *Affordable PTZ option*

Integration

02



- *Plug & Play*
- *Pathway from analog to digital*
- *Multiple mounting options in design*
- *Easy replacement for pre-existing IP cameras*



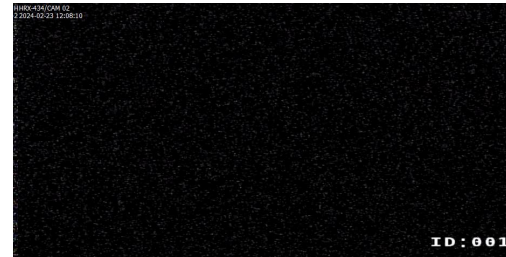
NuClear™ 400

Comparing side-by-side evrCAM vs. 5+ yr old Peclo DD4 (*same date/time stamp, 8 lux*)



NuClear™ 400 vs Pelco | Radiation Test

- Greyscale results, Blackout conditions (0 lux), 15 MV, rate = 200 cGy/min



Cumulative Dose

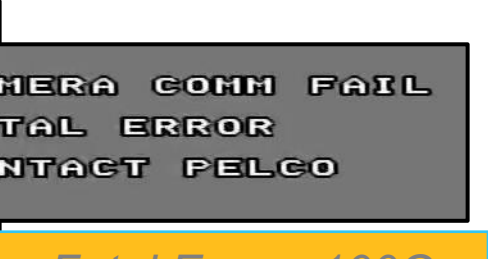
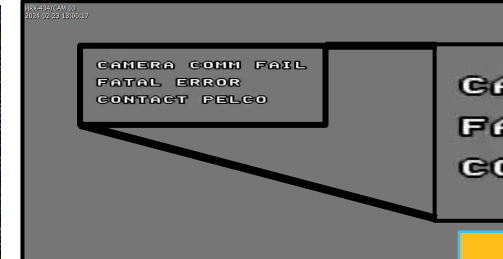
0 Gy

40 Gy

60 Gy

110 Gy

200 Gy



Pelco CCTV
MIRION
Connect 26
AMERICAS

Annual Users' Conference

CAMERA COMM FAIL
FATAL ERROR
CONTACT PELCO

CAMERA COMM FAIL
FATAL ERROR
CONTACT PELCO

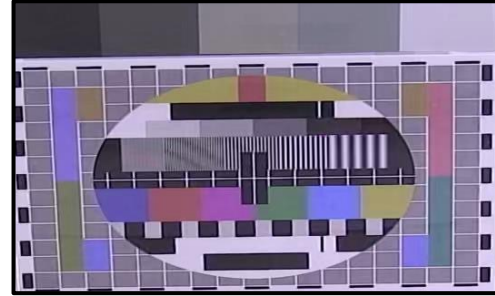
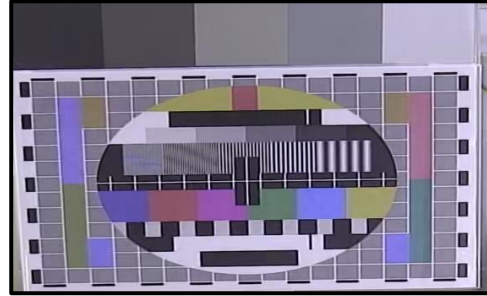
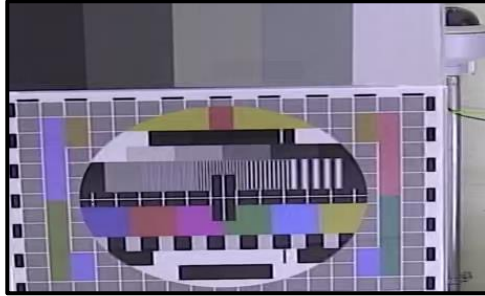
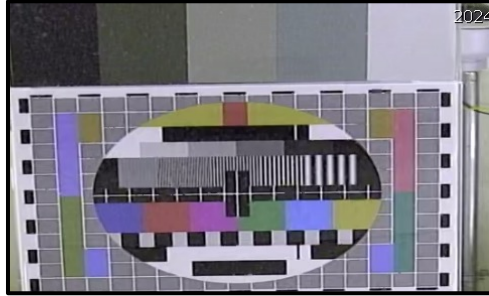
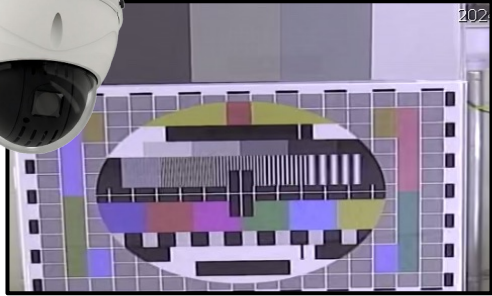
Fatal Error ~100Gy,
camera won't initialize

Empowering Progress.

© 2026 Mirion Technologies. All rights reserved.

NuClear™ 400 vs Incumbent | Radiation Test 15MV

- R/G/B Color test pattern at full light (400 lux), rate = 200 cGy/min



Cumulative Dose

0 Gy

20 Gy
during beam-on

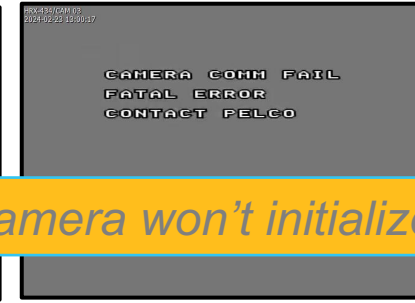
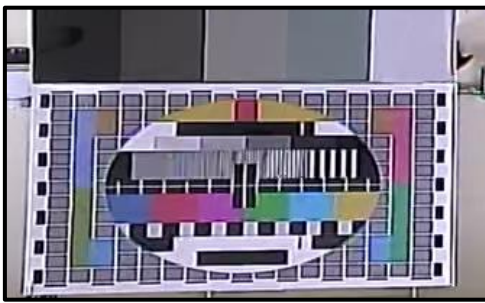
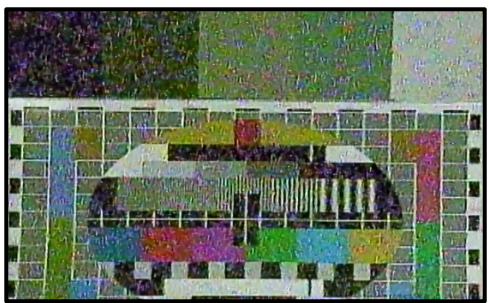
60 Gy

110 Gy

>150 Gy



Incumbent MotionView CCTV



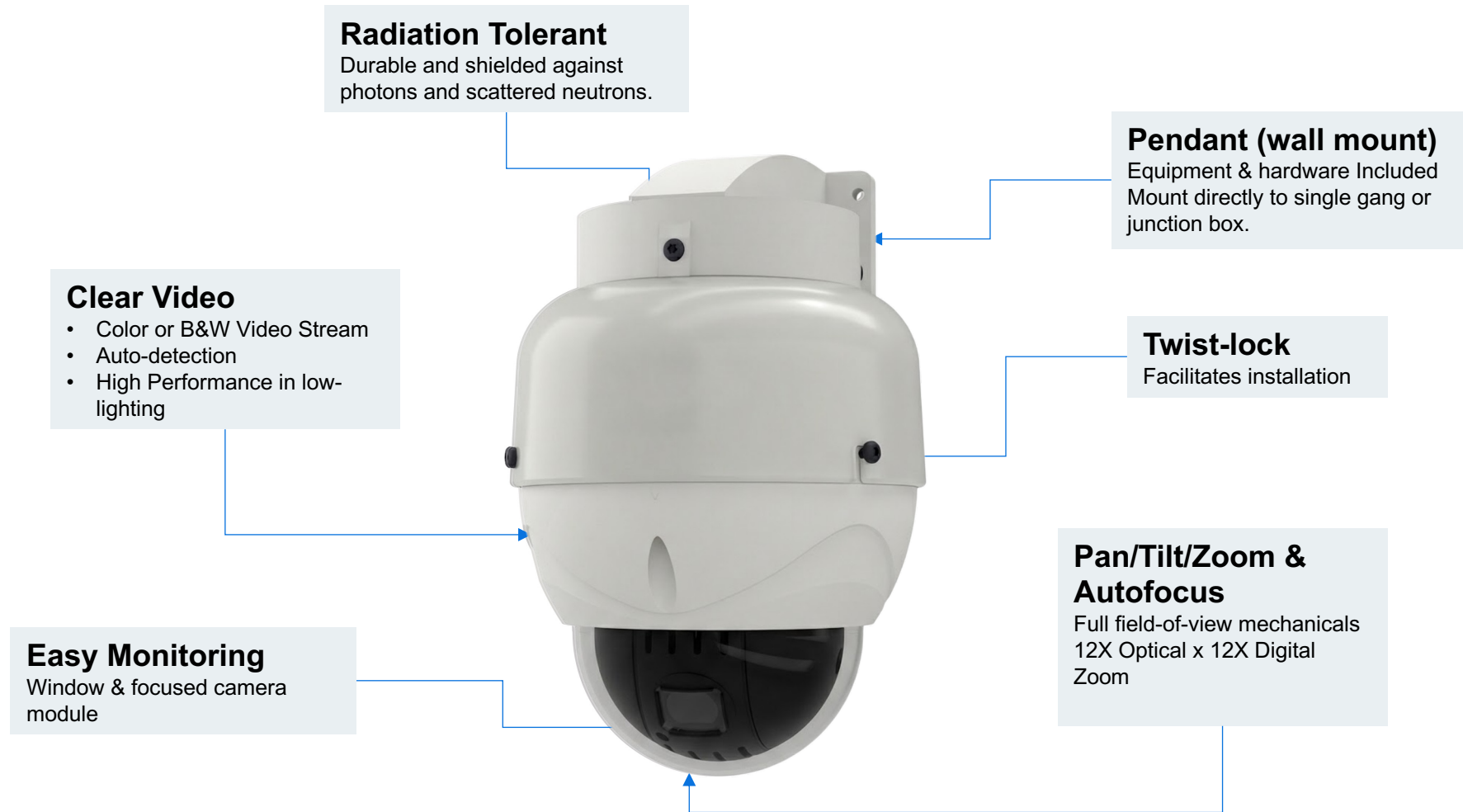
Fatal Error ~100Gy, camera won't initialize

Advancing Radiation Safety.
Empowering Progress.

© 2026 Mirion Technologies. All rights reserved.

3

The Analog User



The Digital User

Digital Controller



Up to 4 Cameras per Controller

- Connector for Ethernet cable (e.g. CAT6)
- Video, power, data interface

Cable Access Port

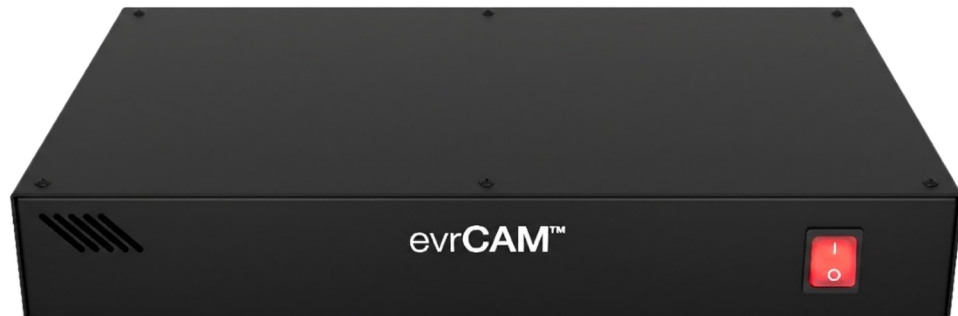
Allows for alternative video & power connections to camera

RJ45/50 plug & play

- Connector for Ethernet cable (e.g. CAT6)
- Video, power, data interface

Mounts direct to ceiling

- Hole and slot patterns adapt to several common ceiling boxes
- Also attaches to included pendant for wall-mounting



NuClear™ 400 Specifications



Radiation Tolerance	200 Gy (20 krad)
PTZ Protocol	Pelco-D (RS-485)
Size, WxDxH	161 x 161 x 205 mm (6.3 x 6.3 x 8.1 in)
Size with pendant, WxDxH	161 x 205 x 254 mm (6.3 x 8.1 x 10 in)
Camera Weight	1.8 kg (4 lbs)
Pendant Weight	0.1 kg (0.3 lbs)

Mechanical & Video

Resolution	2.1 MP
Video Output	TVI: 1920 x 1080p (30/25 fps) CVBS: 720H
Minimum illumination	<0.1 lux (color & black/white)
S/N Ratio	>52 dB
Lens Aperture (f/#)	2.8
Focal length	5 - 64 mm
Brightness	Manual or Automatic
Zoom	12X optical, 12X digital, 144X total
Pan Range	360° continuous
Tilt Range	0° to 180°
Max Speed	360°/s
Screen Flip	Automatic at 90° tilt
Presets	>200 supported

Electrical

Local Power (barrel, bypass)	DC 12V (±10%)
Remote Power (RJ45 or RJ50)	DC 24V (±25%)
Max Current	700 mA
Cabling	CAT5e or better (<150 ft), requires controller for IP
Data Communication	RS-485
Baud Rate	2400 - 57600 bps
Camera Address	001 - 255 (DIP switch)
Protocol	Pelco-D

Digital Controller (optional)

Digital Controller Size, WxDxH	412 x 254 x 71 mm (16.2" x 10" x 2.8")
Digital Controller Weight	2.6 kg (5.7 lbs)
Power Source	DC 24V
Camera Connections	RJ45 (Supports up to 4 cameras)
Server/PC Connector	1x (RJ45)

Environmental & Compliance

Certifications	CE, FCC, IEC 60601-1-2 (Medical EMC), IEC 62368-1
Operating Temperature	0 - 50° C
Operating Relative Humidity	20-80%

NuClear™ 400 vs Pelco



Category	Feature		Pelco® DD4
Camera Adjustments	Pan 360°, Tilt ±90°	●	●
	Zoom	● 12X Optical, 12X Digital	● 10X Optical, 10X Digital
Environment	MV Radiation Tolerance	● 400 Gy	● None
	Low Light Visibility	● <0.1 lux	● 3 lux
Options	Analog Compatibility	●	●
	Digital Compatible over Ethernet	● Plug & Play Digital Controller	● No Digital Solution
	Mounting (wall or ceiling)	●	●

NuClear™ 400

Analog Replacement

01



- Existing analog cable infrastructure
- Power is exchanged or use 12VDC is used
- Replacement of outdated analog system

Analog Upgrade to IP

02



- Existing cable infrastructure to upgrade to IP
- New VMS, Monitor, and accessories
- Replacement of outdated analog system with evrCAM digital controller over CAT5e (or equiv)

Digital IP

03



- Existing cable CAT5e (or equiv)
- Interface with existing 3rd party VMS, monitor, and accessories
- Replacement of IP camera with evrCAM and digital controller

New IP Installation

04



- Use new CAT5e (or equiv) cable
- New VMS, Monitor, and accessories
- New install with evrCAM and controller

NuClear™ 400 Summary

NuClear™ camera

- *Analog solution by itself*
- *Benefits*
 - *More than 3x radiation tolerance, 400 Gy*
 - *Longer life, less replacement cost*
 - *Less waste (e-recycle)*
 - *Backwards compatible, drop-in replacement*
 - *Wall-mount*
 - *Connects to existing wires (coax, cat6)*
 - *Control & view with Varian CCTV display panel*
 - *PTZ via existing Pelco-D protocol*
 - *Preset ready*
- *Improved Visibility*
 - *30x Better low-light visibility (<0.1 vs 3 lux)*
 - *Better digital & optical zoom (12x vs 10x)*



NuClear™ Digital (IP) Solution

- *All-in-one solution*
 - *1-4 cameras, mounts, Digital Controller, PC*, touchscreen monitor*, software* with multi-view*
 - *Includes all evrCAM benefits (see left)*
- *Install Benefits*
 - *Simplify **site planning** to a single cat6 pull & **decrease** installation costs (less time & material)*
- *Improved Customer Experience*
 - *Offer high quality & HD resolution*
 - *HD Resolution @ 1080p vs 470 TVL (incumbent)*
 - *Rad Tolerant camera, better zoom, better low light visibility*
 - *Free-up space at the control console*
 - *Allows single display with multi-view*
 - *Control four cameras from single screen**



Thank you



Survey for:

Radiation-Tolerant Imaging: Elevating Safety and Accuracy



*Please take a moment
to fill out a short survey
on this session.*