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The operational performance of the Yale ESTU

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Abstract. The ESTU began operation in 1988 and achieved the design voltage of 20 MV in 1990. Since that time, improvements to the gas handling system, negative ion injector, accelerator terminal and control system have greatly increased its capability and reliability. Today, the ESTU can efficiently produce an extensive assortment of stable ions at wide-ranging energies in support of low-energy nuclear physics.

Keywords. Negative ion injector; control system; gas handling system.

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1. Introduction

MP-1 was shutdown in 1985 and construction began on the new 20 MV ESTU. The new design incorporated the MP, with an extra section added to each end and a portico, into an enlarged tank. This design was to provide a 50% or greater increase in voltage over the MP. Other MP systems such as gas handling, negative ion injector and terminal were retained with the idea of upgrading each after initial ESTU operation [1]. In 1997, a terminal voltage of 22.3 MV was achieved without accelerator tubes [2]. In 1988, the accelerator tubes were installed and beam was produced for the first experimental run [3]. In 1990, a terminal voltage of 20.9 MV was achieved with Ni and Si beams [4]. Once design voltage was attained, focus shifted to upgrading the retained MP systems.

2. Upgrades

2.1 *Gas handling system*

The ESTU utilizes pure SF_6 as an insulating gas. Due to the properties and expense of the gas, a handling system's design priority must be integrity and personal safety. Since the accelerator may be opened several times during each year for maintenance and repair, it is desirable to minimize transfer times. The original gas handling system suffered from poor workmanship and design. System integrity was poor and transfer times were long.

In 1991, a major effort to correct these problems was completed. Piping was enlarged and lengths reduced. Flow schemes were simplified; an electric heater as well as safety interlocks was installed. This resulted in increased safety to plant and personnel as well as

a significant decrease in transfer times. ESTU evacuation time was reduced from 26 to 18 h. ESTU pressurization was reduced from 28 h to less than 6 h, one-seventh of the original [5].

2.2 *Ion injector*

Proper exploitation of the ESTU required that ions of any mass be selected unambiguously and injected into the accelerator without contamination from neighboring isotopes. Good mass resolution at the negative ion source is therefore essential. When the ESTU was installed, the original MP injector was retained except for a new pre-acceleration power supply and isolation transformers. A new sputter source (Model 860) was also installed but with the 35-degree inflector magnet, mass resolution was limited to 1 in 30.

In 1993, a new injector was installed which included a double focusing, multi-pole corrected 90-degree inflector magnet, lenses, turbo pumps and controls. The mass resolution of the new inflector was 1 in 240. In addition to the Model 860 sputter source, a high intensity helium source was bench tested and installed [6]. In addition to the improved resolution, the new design provided for reduced turnaround times in case of source failure.

By 1997, many improvements were made to the Model 860 sputter source. This included a new gas cathode and cesium reservoir design. These improvements allowed for production of large currents of N and Ca as well as many lanthanide beams [7].

2.3 *Accelerator terminal*

As with the gas handling system and ion injector, the initial ESTU terminal consisted of a foil and gas stripper, and the trim and track focusing left from the MP. Controls of the terminal components were via lucite control rods and servomotors with no provision from data return from the terminal. The new terminal design would incorporate a recirculating gas stripper to be used for intense heavy ion runs, an increased capacity foil changer with isolation valves to avoid disturbing the tubes for foil change, a charge state selector to be used in conjunction with the post-terminal stripper, a GVM for monitoring the voltage difference between the terminal and portico, as well as modern controls and data read backs [6].

In 1997, terminal electronics as well as a terminal GVM was installed and tested. This allowed, for the first time, a true terminal voltage measurement. Previously, the terminal voltage was inferred from a GVM, which measured portico voltage. In 1998, the new mechanical terminal assembly was installed and tested. Foils could now be changed without venting the tubes to atmosphere, which reduced reconditioning times. Gas stripping could be accomplished without overloading ion pumps [6]. Charge states could be resolved for both double-stripping operations and beam diagnostics [8].

2.4 *Control system*

Although the basic control software and CAMAC hardware are the same as originally installed with the ESTU, several revisions have been made. Several versions of the original

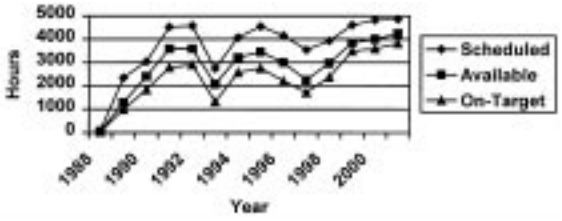

Figure 1. Beam times for the years 1988–2001.

software have been implemented as control parameters were added or deleted. This home-built software has proven to be extremely reliable where not a single day of operation has been lost due to problems. The CAMAC hardware has also undergone revisions. New driver units, necessary to distribute signals between the control room and accelerator vault, have been designed in-house and installed. The new terminal electronic system consists of a CAMAC crate enclosed in a double screen enclosure. The terminal crate communicates with the control computer via an IR link [9]. The reliability of the terminal electronics has been excellent.

3. Operational performance

3.1 *Beam time*

Scheduled beam time, beam available time and beam on-target time is summarized in figure 1 for the years 1988–2001. Operational records for these have been achieved in each of the last three years. Beam times were relatively low in 1997 due to the construction of several new experimental stations and in 1993 during the installation of the new ion injector.

3.2 *Voltage capabilities*

The ESTU voltage performance has been excellent as long as the SF_6 inventory is maintained. In 1990, a record 20.9 MV with beam was achieved. Since an SF_6 addition in 1997, the ESTU has again been taken above 20 MV at least once in each of the successive years. Voltages up to 18 MV are achieved with little or no conditioning. Voltages up to 19 MV require minimal conditioning while voltage up to 20 MV require as little as 24 h to achieve. In figure 2, beam available hours are given for each year following SF_6 addition.

3.3 *Available beams and energies*

Since 1998, 71 isotopes of 32 elements have been accelerated for experimental runs. Twenty three isotopes had natural abundances less than 10%, while 5 were less than 1%. The lowest energy attained is 2.2 MeV Li, while the highest energy was 345 MeV Ni. Table 1 lists the available beams from the ESTU, natural or enriched abundances used, along with the energy range and typical analyzed beam for previous runs.

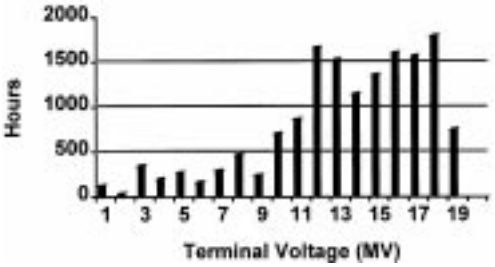

Figure 2. Beam available at various voltages for the years 1998–2001.

Table 1. Ion beams accelerated for experiments.

Ion	Isotope	Abund. (%)	Energy range (meV)	Analyz. current (pnA)	Ion	Isotope	Abund. (%)	Energy range (meV)	Analyz. current (pnA)
H	1	99.985	8–38	3600	Ni	62	3.59	100–335	1
	2	99*	30	233		64	0.91	320–335	0.3
He	3	50*	42–57	242	Ge	70	20.5	160	0.1
	4	99.999	20–43	27	Se	74	0.9	230–262	1
Li	6	7.5	42	50		76	9	170–253	3
	7	92.5	2.2–60	490		78	23.5	230	1
Be	9	100	35–45	3		80	49.6	230–236	4
B	10	19.8	31–100	312		82	9.4	230	1
	11	80.2	20–80	171	Br	79	50.69	240–290	2
C	12	98.89	27–114	252		81	49.31	290	2
	13	50*	55–90	106	Zr	90	51.45	269–341	2
N	14	99.63	42–100	184		91	11.27	300	0.6
	15	99.9*	70–82	243		94	17.33	250–300	3
O	16	99.76	10–126	1040		96	2.78	250–284	1
	18	99*	5–150	1286	Mo	94	9.25	300	0.7
F	19	100	25–108	65	Ru	96	5.52	280	0.7
Mg	24	78.99	130–166	4	Te	120	0.096	220	0.1
	26	11	120–124	4		124	4.816	220	0.8
Al	27	100	119–146	7		126	18.95	340	0.2
Si	28	92.23	5.5–180	200		128	31.69	302–340	1
	29	4.67	142–144	5	Nd	142	27.13	190–260	1
	30	3.1	135–160	4		144	23.8	240–288	0.7
S	32	95.02	60–170	48		145	8.3	190	0.1
	34	4.21	130–175	6		146	17.19	240–305	0.4
Cl	35	75.5	160–185	50		148	5.76	240–305	0.1
	37	24.5	120–215	36		150	5.64	240–282	0.2
Ca	40	96.94	82–204	57	Sm	152	26.7	220	0.3
	42	0.647	180	0.2	Yb	170	3.05	200	0.1
	44	2.086	180–185	0.5		174	31.8	160–200	1
	48	0.187	185	0.02	W	184	30.67	256	0.3
V	51	99.8	200–220	5	Os	188	13.3	267–270	0.7
Cr	50	4.35	150–200	1		189	16.1	268	0.1
	52	83.79	200–220	7		190	26.4	200–250	0.7
Fe	54	5.8	235–250	0.1		192	41	270	1
Ni	58	68.27	200–345	15	Au	197	100	259–480	1
	60	26.10	200–345	13					

4. Conclusion

The design of the ESTU accelerator has allowed reliable and routine terminal voltages up to 20 MV. The continued expansion of the capability of the ESTU, through upgrades to the gas handling system, ion injector, terminal and control system have enabled the ESTU to efficiently produce an extensive assortment of stable ion beams at wide-ranging energies.

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